Ralphs Grocery EC-Diesel™ Truck Fleet

Final Results

Produced for the U.S. Department of Energy (DOE) by the National Renewable Energy Laboratory (NREL), a U.S. DOE national laboratory

DOE/NREL Truck Evaluation Project

RALPHS GROCERY COMPANY EC-DIESEL™ TRUCK FLEET: FINAL RESULTS

Truck Evaluation Project

by

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Executive Summary

Ralphs Grocery Company, one of the largest supermarket retailers in the western United States, has operated in California since 1873. Ralphs is headquartered in Los Angeles and is a division of the Kroger Company (the nation's largest food retailer), based in Cincinnati, Ohio.

The U.S. Department of Energy's Office of Heavy Vehicle Technologies sponsored a research project to collect and analyze data on the performance and operation costs of 15 of Ralphs Grocery's diesel trucks fueled by Emissions Control Diesel (ECD™, also known as EC-Diesel™) or a related fuel, ECD-1, in commercial service, compared with the performance of 5 diesel trucks fueled by California Air Resources Board (CARB) diesel fuel and operating on similar routes. The National Renewable Energy Laboratory managed this project.

This evaluation was part of the larger EC-Diesel™ Technology Validation Program sponsored by ARCO (a division of BP) to evaluate ECD™ (an ultra-low-sulfur diesel [ULSD] fuel) and passive regenerative catalyzed diesel particulate filter (DPF) technology on urban diesel vehicles. DPFs are intended to replace the original equipment muffler system and remove harmful emissions from the truck exhaust stream. ECD™ is intended to provide improved emission control and performance characteristics.

ARCO produced 1 million gallons of ECD™ for this program. The fuel's performance, impact on engines, and emission characteristics were evaluated in several fleets, ranging from the San Diego School District to Hertz Equipment Rental to Los Angeles City Sanitation, and involving more than 150 vehicles. Nearly half these vehicles were retrofitted with passive regenerative catalyzed DPFs. Partners with ARCO in this effort included

- California Air Resources Board
- California Energy Commission
- Corning Inc.
- Cummins Engine Company
- Detroit Diesel Corporation
- Engelhard Corporation
- Fleetguard/Nelson
- Ford Motor Company
- International Truck and Engine Corporation
- Johnson Matthey International
- National Renewable Energy Laboratory
- NGK-Locke Inc.
- South Coast Air Quality Management District
- University of California-Riverside
- West Virginia University

Other participants and suppliers are listed in the *Ralphs Grocery EC-Diesel™ Truck Fleet Final Data Report* (Battelle, September 2001).

Objective

To provide transportation professionals with quantitative, unbiased information on the cost, maintenance, operational, and emission characteristics of ECD™, alone and in combination with two after-market filters, as alternatives to conventional CARB diesel fuel for heavy-duty trucking applications.

This information should also benefit decision makers by providing a real-world account of the obstacles overcome and lessons learned in adapting advanced emission control fuels and technologies to a commercial transportation site previously geared toward conventional CARB diesel trucks.

Method

The study design involved the side-by-side comparison of data from 20 trucks: 5 were fueled with conventional CARB diesel and 15 with ECD™. The ECD trucks were further divided into 3 groups of 5 to compare the performance of two types of passive regenerative catalyzed DPFs:

- ECD™ only (no DPF)
- ECD™ plus a Johnson Matthey CRT™ filter
- ECD™ plus an Engelhard DPX™ filter

Daily data were gathered from fuel and maintenance tracking systems for more than one year. Examples of the data parameters included:

- Fuel consumption
- Mileage and dispatching records
- Engine oil additions and oil/filter changes
- Preventive maintenance action records
- Records of unscheduled maintenance (such as roadcalls) and warranty repairs.

The data collection was designed to cause as little disruption for Ralphs as possible. In general, Ralphs staff sent electronic or paper copies of data collected as part of normal business operations to an NREL contractor for analysis.

Results and Lessons Learned

Based on this evaluation, we conclude the following major points related to start-up issues, 12-month testing in service, and emissions testing on the portable chassis dynamometer (performed by West Virginia University).

Start-Up Issues

- Understanding the actual duty cycle to which passive regenerative catalyzed DPFs will be exposed is critical for proper operation and for determining service intervals. Users may need special equipment to clean their own filters and handle the material removed from the filter.
- The DPFs are larger and heavier than most original equipment manufacturer mufflers, which the DPFs are intended to replace. Therefore, engineering is required to properly install and support the filters.
- No changes, other than a separate fuel storage tank, were required for the Ralphs facilities (only needed to support the test fleet).
- Ensuring that only ECD™ fuel was used for the filter retrofitted trucks was important to properly operate the DPFs.

In-Service 12-Month Evaluation

- Trucks that were equipped with DPFs and fueled by ECD™ operated reliably for more than 100,000 miles and had no filter-related issues that required the trucks to be taken out of service.
- The diesel and ECD™ trucks were operated in essentially the same duty cycle and had average monthly mileage of 7,324–10,104 miles.
- The fuel economy results do not indicate a fuel economy penalty for using DPFs in this application. The in-service fuel economy results are consistent with the lower energy content of the ECD™ fuel used.
- In general, engine oil consumption was low for all study trucks. This was key to extending the service interval of the DPFs from 60,000 miles to 150,000 miles for this evaluation.
- The use of DPFs and ULSD fuel caused a 3%–4% increase in maintenance costs (related to securing the exhaust stack) to maintain the filter system.
- The overall operating cost per mile showed a 3%–4% higher cost for operating the ECD™ and retrofitted trucks than for the CARB group. The extra cost

was related to repairing and securing the filters and to differences in fuel energy content. The fuel cost used in this analysis, however, did not include the \$0.05–\$0.10 increased cost per gallon for the ECD™ fuel, which were covered by ARCO for the duration of the project.

Emission Testing

- The retrofitted trucks using ULSD fuel had significantly lower particulate matter (PM), hydrocarbons (HC), and carbon monoxide (CO) emissions. Many readings were at or below the detection limit of the measuring equipment. The CO results varied depending on the test cycle. The carbon dioxide emissions were variable, but about the same overall as for the CARB diesel. The fuel economy values were about the same.
- All 20 study trucks were operated about 150,000 miles between the two rounds of emission testing. None of the 10 retrofitted trucks had the filters cleaned or serviced. Some variation and degradation in the emission control results were observed between the rounds. However, the DPF equipped trucks had much lower emissions for PM, HC, and CO during the second round compared to the non-DPF equipped trucks.

Future ECD™ Operations at Ralphs Grocery Company

Ralphs remains committed to emission control in its trucking operation, and continues to investigate and search for funding to convert the entire fleet of diesel trucks at the Riverside Service Center to ECD-1 and DPFs. Ralphs converted the filter-equipped trucks from ECD™ to ECD-1 fuel in July 2001. Nine of the 10 DPF retrofitted trucks have operated 140,000–180,000 miles without having the filters cleaned.

Overview

Ralphs Grocery Company, in operation since 1873, is one of the largest supermarket retailers in the western United States, with 450 conventional and warehouse-style supermarkets. Ralphs is a division of The Kroger Company, headquartered in Cincinnati, Ohio. Kroger reported $49 billion in sales for 2000. From its Riverside, California, Service Center, Ralphs operates 150 Class 8 diesel tractors for food and grocery distribution between its warehouses and retail locations.

As part of a 12-month multifleet evaluation of EC-Diesel™ (ECD™) fuel, Ralphs tested and collected detailed data on 20 Sterling trucks (model year 1999). The trucks were equipped with Detroit Diesel Series 60 engines operating from Ralphs Riverside Service Center. They were divided into four study groups according to the fuel used and their exhaust filter equipment:

- California Air Resources Board (CARB) group – Five trucks with the original equipment manufacturer (OEM) muffler, using CARB diesel fuel (control group)
- ECD™ group – Five trucks with the OEM muffler, using ECD™ fuel
- DPX™ group – Five trucks retrofitted with Engelhard DPX™ passive regenerative catalyzed diesel particulate filters (DPFs), using ECD™ fuel
- CRT™ group – Five trucks retrofitted with Johnson Matthey continuously regenerating technology (CRT™) passive regenerative catalyzed DPFs, using ECD™ fuel.

ECD™ fuel was used in 15 of the 20 trucks during the evaluation period. The use of ECD™ rather than CARB diesel was necessary for the passive regenerative catalyzed DPFs. CARB diesel's higher sulfur content would have temporarily degraded the ability of the catalyst to reduce emissions.

Why Low-Sulfur Diesel Fuel?

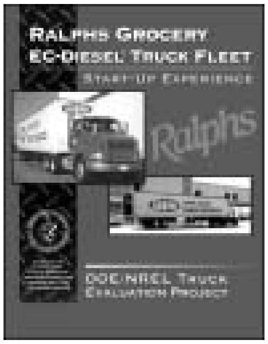
In May 2000, the U.S. Environmental Protection Agency (EPA) proposed stricter emission standards for heavy-duty diesel vehicles and reductions in the sulfur content of diesel fuel. EPA plans to require that the maximum sulfur content of highway diesel fuel be reduced to 15 ppm, approximately 97% below the current maximum level of 500 ppm. EPA also proposes requirements that will reduce smog-causing oxides of nitrogen (NO_x) by 95% and particulate matter (PM) by 90%.

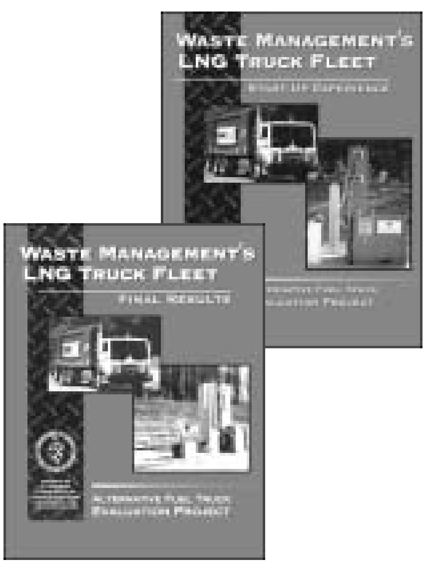
On August 1, 2000, EPA issued a final rule for the first phase of its two-part strategy to significantly reduce harmful diesel emissions from heavy-duty trucks and buses. The first phase deals exclusively with cleaner truck engines, which must emit 40% less air pollution beginning in 2004. The second phase, issued in 2001, requires cleaner diesel fuels and engines by 2007.

These tougher standards apply to heavy-duty trucks that run on either diesel fuel or gasoline. Diesel fuel needs to be "significantly cleaner than it is today," according to EPA's news release issued May 17, 2000.

The ARCO EC-Diesel™ Technology Validation Program tested heavy-duty vehicles using cleaner diesel fuel and pollution control technologies, both of which are vital to meeting the new EPA standards. Additional information is available on the EPA Web site *http://yosemite.epa.gov/opa/admpress.nsf*.

In California, CARB has proposed additional measures to reduce PM emissions from diesel-fueled engines. These measures are summarized in the Final Draft Proposed Risk Reduction Plan for Diesel-Fueled Engines and Vehicles at *http://www.arb.ca.gov/diesel/documents/rrpFinal.pdf*. The South Coast Air Quality Management District passed a regulation (Rule 1196) for on-road heavy-duty public fleet vehicles. New public fleets or public fleets adding new vehicles are required to purchase or lease alternative fuel heavy-duty engine or vehicles or dual-fuel heavy-duty vehicles effective July 1, 2002.





The purpose of this report is to provide transportation professionals with summary information on the cost, maintenance, operational, and emissions characteristics of ECD™ and catalyzed particulate filters compared with conventional CARB diesel fuel for heavy-duty trucking applications. The report should also benefit decision makers by providing a real-world account of the obstacles overcome and the lessons learned in adapting ECD™-fueled trucks to a site previously geared toward conventional diesel trucks.

This report summarizes the results of the ECD™ study at Ralphs Grocery. Further technical background, research methods, extensive original data, and detailed discussions are presented in *Ralphs Grocery EC-Diesel™ Truck Fleet Final Data Report* (Battelle, September 2001).

Heavy Vehicle Evaluation Projects at DOE and NREL

On behalf of the U.S. Department of Energy (DOE), the National Renewable Energy Laboratory (NREL) managed the data collection, analysis, and reporting activities for the Ralphs ECD™ truck evaluation. NREL is a DOE national laboratory.

One of NREL's missions is to assess the performance and economics of advanced technology vehicles objectively so that

- Fleet managers can make informed decisions when purchasing advanced technology vehicles.
- Advanced technology vehicles can be used more widely and successfully to reduce U.S. consumption of imported petroleum and to benefit users and the environment.

NREL and several companies across the United States are evaluating advanced technologies. Fuels include liquefied natural gas, compressed natural gas, liquefied petroleum gas (propane), biodiesel, low-sulfur diesel, and ethanol. Hybrid-electric vehicle technology is also being evaluated.

The Truck Evaluation Project

The overall objective of the ongoing DOE/NREL Truck Evaluation Project is to compare heavy-duty trucks using advanced technologies with those using conventional diesel fuel. Specifically, the project seeks to provide comprehensive, unbiased evaluations of the newest generation of advanced vehicle technologies.

NREL has collected and analyzed data on heavy-duty advanced technology trucks throughout the United States since 1996. The program currently has 5 demonstration sites and continues to add new sites for further data collection and evaluation. Other evaluation sites are

- Raley's (Sacramento, California)
- Orange County Sanitation District (Fountain Valley, California)
- United Parcel Service (Hartford, Connecticut)
- Waste Management (Washington, Pennsylvania)

Sites are selected according to the type of advanced technology in use, the types of trucks and engines, the availability of diesel comparison (control) vehicles, and the host site's interest in using advanced vehicle technologies. After analysis, peer review, and DOE approval, results from each site are published separately.

Host Site Profile: Ralphs Grocery Company in Riverside, California

The host site for this study was the Riverside, California, facility of Ralphs Grocery Company. This center, home to 150 tractors, is one of three Ralphs facilities that serve the Los Angeles area (Figure 1). The Riverside location provided adequate space for adding temporary fueling for the ECD™ and space for on-site emission testing by West Virginia University (WVU).

ARCO recommended that Ralphs Grocery Company participate in the ECD™ project. Ralphs formally joined the project in August 1999.

After the ECD™ fuel became available at the Riverside Service Center in mid-January 2000, passive regenerative catalyzed DPFs were installed on 10 of the 20 study trucks at Ralphs in January and February 2000. The data collection and evaluation were started March 1, 2000, after all filters were installed and in operation. A 12-month evaluation was conducted through February 28, 2001. The data presentations in this report focused on this period.

Ralphs ECD™ Trucks

For the ECD™ project, 20 Sterling AT9513 trucks, model year 1999, were chosen. These trucks (ID numbers 5900 through 5920, except for 5916, which was out of service because of an accident) were the first received from an order of 50. This fleet started regular service at Ralphs in October 1998. The trucks had mileages of 139,000–189,000 miles at the start of the evaluation period, and 240,000–304,000 miles at the end.

Figure 1. Ralphs distribution facilities in the Los Angeles area

As shown in Table 1, the 15 ECD™ and the 5 CARB diesel trucks were equipped with Detroit Diesel Series 60 engines and Fuller RTX14710C transmissions. The engines were built and certified to 1998 standards. Figure 2 shows 2 ECD™ test trucks at Ralphs.

Ralphs ECD™ trucks operated on the same duty cycle as the rest of the fleet, which was daily city and suburban grocery distribution service in the Los Angeles area. Each truck was used as many as 7 days per week and 2 shifts per day. The 20-truck evaluation fleet served 3 to 6 retail stores per day.

The filters were installed in place of the OEM muffler with no engine modifications. The DPX™ and CRT™ filters and assemblies were

Table 1. Vehicle Systems Description

Feature	Descriptions
Chassis Manufacturer/Model	Sterling AT9513
Chassis Model Year	1999
Engine Manufacturer/Model	Detroit Diesel Series 60
Emission Certification Year	1998
Engine Ratings Max. Horsepower Max. Torque	 430 hp @ 1800 rpm 1550 lb-ft @ 1200 rpm
Fuel System Storage Capacity	215 gallons
Transmission Manufacturer/Model	Fuller RTX14710C
Tractor Curb Weight	15,880 lb
Gross Vehicle Weight (GVW/GCW)	46,000/80,000 lb
Catalyzed Particulate Filters	Johnson Matthey CRT Engelhard DPX
EPA Engine Family Name	WDDXH12.7EGD

Figure 2. ECD™ test trucks at Ralphs

custom designed for the grocery trucks, taking into account the engine model, performance, and duty cycle.

Figure 3 shows one study truck without a DPF installed, one with the Johnson Matthey CRT™ installed, and one with an Engelhard DPX™ installed. The DPX™ filter is about 3 inches larger in diameter than the OEM muffler, but is about the same length. The CRT™ filter is about 4 inches larger in diameter and twice as long as the muffler it replaced.

In both cases, the larger diameter caused concerns about clearance with the cab and possible obstruction to the passenger side mirror. Both filter systems weigh significantly more than the OEM mufflers. These factors caused concern with vibration and securing the exhaust stack, but were not significant enough to change the fuel economy.

The CRT™ installation required a change to the securing arm attachment point on the exhaust stack and new brackets and clamps. The DPX™ installation required some modification to the original clamps. The DPFs replaced the OEM mufflers and performed the same noise reduction role.

The cost to purchase each truck in the project was the same. The passive regenerative catalyzed DPF retrofits, which were done on 10 trucks in January and February 2000, cost about $6,000 each. Current filter installation costs are estimated to be $5,000–$6,000 for this size truck and engine.

Catalyzed DPF Technology

Two passive regenerative catalyzed DPF systems were evaluated. Selected vehicles were retrofitted with either an Engelhard catalytic soot filter (DPX™) or a Johnson Matthey CRT™ filter. Illustrations of a CRT™ filter and details of the filter substrate are shown in Figure 4.

The Engelhard DPX™ is a platinum and base metal oxide catalyst-coated ceramic wall-flow filter. The catalyst coating is impregnated into the porous filter walls of the element and promotes the oxidation of collected particulate matter (PM), hydrocarbons (HC), and carbon monoxide (CO). When exhaust gas temperatures are 375°C at least 25% of the time, this filter makes it possible to "burn" the soot on contact with a proprietary catalyst coating. This process occurs when a wall-flow monolith filter is used to trap the PM.

The Johnson Matthey CRT™ filter is a two-stage system that features a platinum-loaded oxidation catalyst followed by an uncoated ceramic wall flow-filter. The catalyst continuously oxidizes some of the nitric oxide emitted from the engine to nitrogen dioxide (NO_2). The NO_2 reacts with the soot collected on the filter at a lower temperature (250°C), thereby lowering the exhaust gas temperature needed to regenerate the PM collected on the filter element.

Diesel fuel with a 50-ppm maximum sulfur content is recommended for both DPF systems tested. Diesel fuel with a maximum sulfur content of 15 ppm (ARCO ECD-1) is now commercially available in California for $0.05–$0.10 per gallon more than typical CARB diesel fuel. The ECD™ fuel used in this project had about 7 ppm sulfur content.

The DPX™ and CRT™ filters have a recommended service (cleaning) interval of 60,000 miles or 12 months of operation, whichever comes first. The life of the filter is intended to be the same as the life of the engine. Users should monitor the filter backpressure carefully and watch for maintenance incidents, such as a catastrophic turbocharger failure, in which the engine may allow significant engine oil to pass to the filter.

For this project, the filters were installed with no engine modifications. The vehicles were fueled exclusively with ECD™ fuel using a segregated bulk storage fuel tank.

Figure 3. OEM muffler and DPF filters as installed. Left to right: No DPF installed; CRT™ installed; DPX™ installed

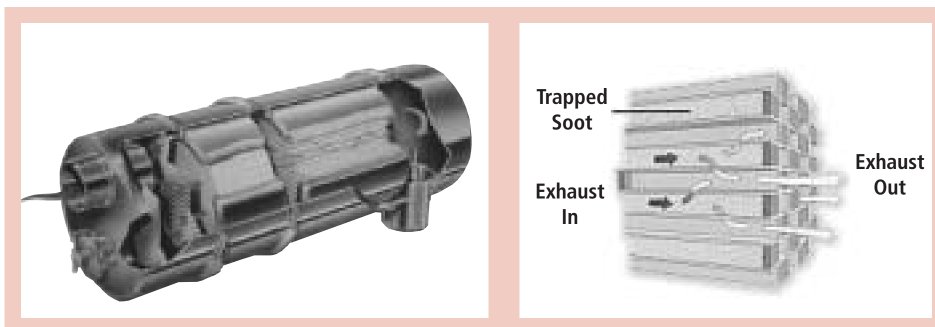


Figure 4. Johnson Matthey CRT™ (left) and typical filter substrate (right)

Project Design and Data Collection

Data were gathered from Ralphs' fuel and maintenance tracking systems daily. Examples of the data parameters included

- Fuel consumption by vehicle and fill
- Mileage data from every vehicle
- Dispatching logs
- Engine oil additions and oil/filter changes
- Preventive maintenance action (PMA) work orders, parts lists, labor records, and related documents
- Records of unscheduled maintenance (such as road calls)
- Records of repairs covered by manufacturer warranty

The data collection was designed to cause as little disruption for Ralphs as possible. Ralphs staff sent electronic or paper copies of data collected as part of normal business operations to an NREL contractor for analysis.

Ralphs staff had access to all data collected from the site and other data available from the project. Data summaries, evaluations, and analyses were distributed to designated staff for review and input.

The study design included tracking safety incidents that affected the vehicles or occurred at Ralphs fueling stations or in the maintenance facilities. However, no safety incidents were reported during the data collection period.

Ralphs Grocery Company's Facilities and Bulk Fuel Storage

From its Riverside facility, Ralphs operates 150 grocery trucks over 5 counties in the Los Angeles area. The truck operations facility covers 80 acres (the warehouse is 1.1 million square feet) and employs a staff of more than 700.

The CARB diesel trucks are fueled by two 20,000-gallon underground diesel fuel storage tanks and two dispensing lanes at the Riverside Service Center (see Figure 5).

Figure 5. **CARB diesel fueling station**

A separate above ground temporary storage tank for ECD™ was located near the diesel fueling facility at Riverside. Gaining local building code approval to install this tank took several months. Ultimately, ARCO provided a 2,000-gallon temporary fuel tank to Ralphs for this project (Figure 6).

Figure 6. **Temporary fueling station for ECD™ fuel**

Locking fuel caps were used to ensure that the 15 study trucks were fueled with ECD™ only. A label warning that a truck was to be fueled with ECD™ only was placed above the fueling location on the step just below the cab door (Figure 7). Because the 2,000-gallon tank was smaller than originally planned, Fleet Fuels (under contract to NREL) delivered ECD™ as often as four times per week.

ARCO covered the costs of the temporary fuel tank and the extra cost for fuel delivery on demand. If Ralphs converts the entire Riverside fleet to low-sulfur diesel fuel, the temporary fuel tank will not be required and the delivery

Figure 7. Locking fuel cap and ECD™ reminder sign

Figure 8. Ralphs' maintenance facility

costs will not apply. Therefore, the extra costs were not considered in the cost analyses.

The maintenance facility at Ralphs is shown in Figure 8. No modifications or extra costs (other than those associated with the temporary fuel station) were incurred to accommodate the ECD™ fuel.

Project Start-Up at Ralphs

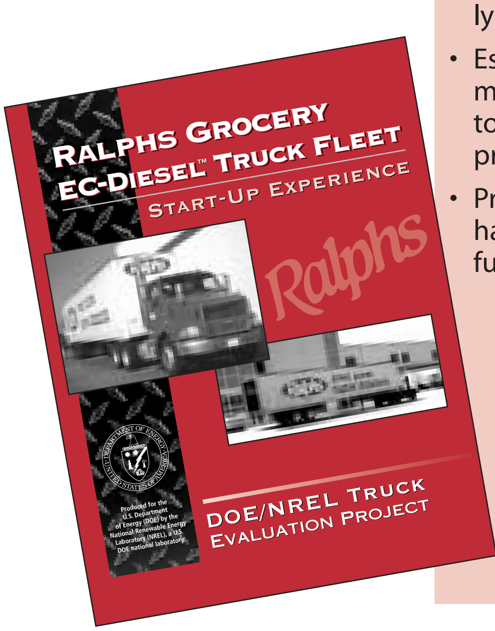
The vehicles for this project began operating in October 1998. The evaluation proceeded smoothly, according to Ralphs' management staff. Drivers noticed that the exhaust from the ECD™ trucks was much cleaner than that from conventional diesel trucks.

Issues identified during start-up included:

- The user of the passive regenerative catalyzed DPFs is responsible for servicing the filters, and therefore will need to consider on-board monitoring of backpressure to protect the filter and the engine. Maintenance repairs caused by improperly servicing the filters will most likely not be covered by the filter or engine warranty.

Lessons Learned at Start-Up

- Obtain corporate commitment to support participation in the program. Managers at other test sites found that the benefits of converting to cleaner fuels will not be immediate or universally recognizable.
- Identify a "champion" in the company. The Riverside operations staff received the initial go-ahead from the group vice president who, along with line managers, is given periodic updates.
- Be prepared to explain the value of participating in a cleaner fuels demonstration. Check Web sites for active companies and projects (*http://www.nrel.gov*, *http://www.ott.doe.gov*, or *http://www.afdc.doe.gov*).
- Take a "team approach." Select drivers interested in the test program and build a support team of drivers, maintenance staff, and managers, who are willing to work together.
- Ensure the site's maintenance data systems are adequate for reporting purposes.
- Periodically review maintenance reports for new fuel-related issues.
- Analyze the space requirements and amount of test diesel fuel needed before installing the tank.
- Consider retrofit effects. For example, the filters were heavier and larger than the original equipment. The larger filters required a different mounting bracket design, and the possible visual obstruction of the right-side mirrors had to be considered.
- Use lockable fuel caps to prevent accidental refueling with another fuel. Fuels with higher than recommended sulfur levels can "poison" the catalyst and temporarily reduce emission control effectiveness.
- Establish and maintain good communications with drivers, refuelers, maintenance staff, and scheduling personnel. Memos were initially sent to crews at Ralphs to explain the program, and periodic updates were provided.
- Provide information to drivers, refuelers, and others concerned about handling practices or risks. Except for emissions, the low-sulfur diesel fuels at Ralphs were essentially the same as the previous fuel.
    - Periodically survey participating drivers for their evaluations of the fuels and engine effects.
    - Inform key stakeholders about your company's role in improving air quality.
    - Consider other funding sources to reduce the costs to the participating company.
    - Develop a process to measure how vehicles performed after their conversions compared with their normal performance.



Ralphs Grocery Start-up EC-Diesel™ Truck Fleet Experience report is available online at *http://www.ott.doe.gov/heavy_vehicle* or from the National Alternative Fuels Hotline at 800-423-1363.

- Understanding the duty cycle to which the filter will be exposed is critical for proper operation. Filter suppliers can help users determine service intervals and procedures for the fleet and operations by considering the vehicle duty cycle, typical engine oil consumption, and service environment.

  The user may have the filters serviced in one of three ways:

  - Service the filter in-house (may require special equipment for handling the material removed from the filter during cleaning).
  - Send one filter out for cleaning, and use an extra one in the vehicle.
  - Send the truck to a dealer or maintenance shop to have the filter cleaned.

- The filters are intended to replace the muffler and are larger and heavier than most OEM mufflers. Therefore, engineering is required to properly install and support the filters for a specific truck and engine model.

For the Ralphs evaluation, the filters were custom installed. New fleet operators retrofitting trucks with filters will purchase kits with the proper equipment for their trucks. An experienced service company should install the filters.

- A local engine dealership easily installed the filters for the Ralphs trucks.
- A segregated fuel storage tank and lockable fuel caps on the trucks worked well for this project, to help ensure the correct fuel was used. Methods for controlling the consumption of higher sulfur fuel must also be considered until ultra-low sulfur diesel (ULSD) is available everywhere. Drivers and fuelers must be trained. The use of higher sulfur diesel fuel (>50 ppm sulfur) does not permanently damage the filters, but temporarily reduces the effectiveness of the catalysts.

Evaluation Results

The analyses in this report cover 15 ECD™ trucks and 5 CARB diesel trucks operating during the 12-month evaluation period (March 1, 2000, through February 28, 2001).

Truck Use in Grocery Hauling Service

The Ralphs trucks were used for urban and suburban food and grocery distribution as many as 7 days per week, 2 shifts per day. The trucks depart the Riverside facility loaded and return nearly empty, unless they stop to back-haul goods to the Riverside facility. The Ralphs trucks averaged 37–40 mph throughout the period.

Throughout the evaluation period, the CARB diesel and the ECD™ vehicles did the work Ralphs expected.

Figure 9 shows the monthly average miles traveled for the fleet. The ECD™ trucks averaged 9,150 miles; the CARB diesel trucks 8,604 miles. Figure 10 shows fleet trends in average monthly miles driven, including some time before the evaluation.

Fuel Energy and Content

According to a fuel analysis performed by Southwest Research Institute as part of the emission testing, the ECD™ fuel has 2.4%–2.8% less energy content per gallon than the CARB diesel. Table 2 shows the fuel analysis results for CARB diesel, the ECD™ fuel used in this evaluation, and BP's commercial ECD-1 fuel.

Tests were conducted in accordance with the standard methods of the American Society for Testing and Materials (ASTM).

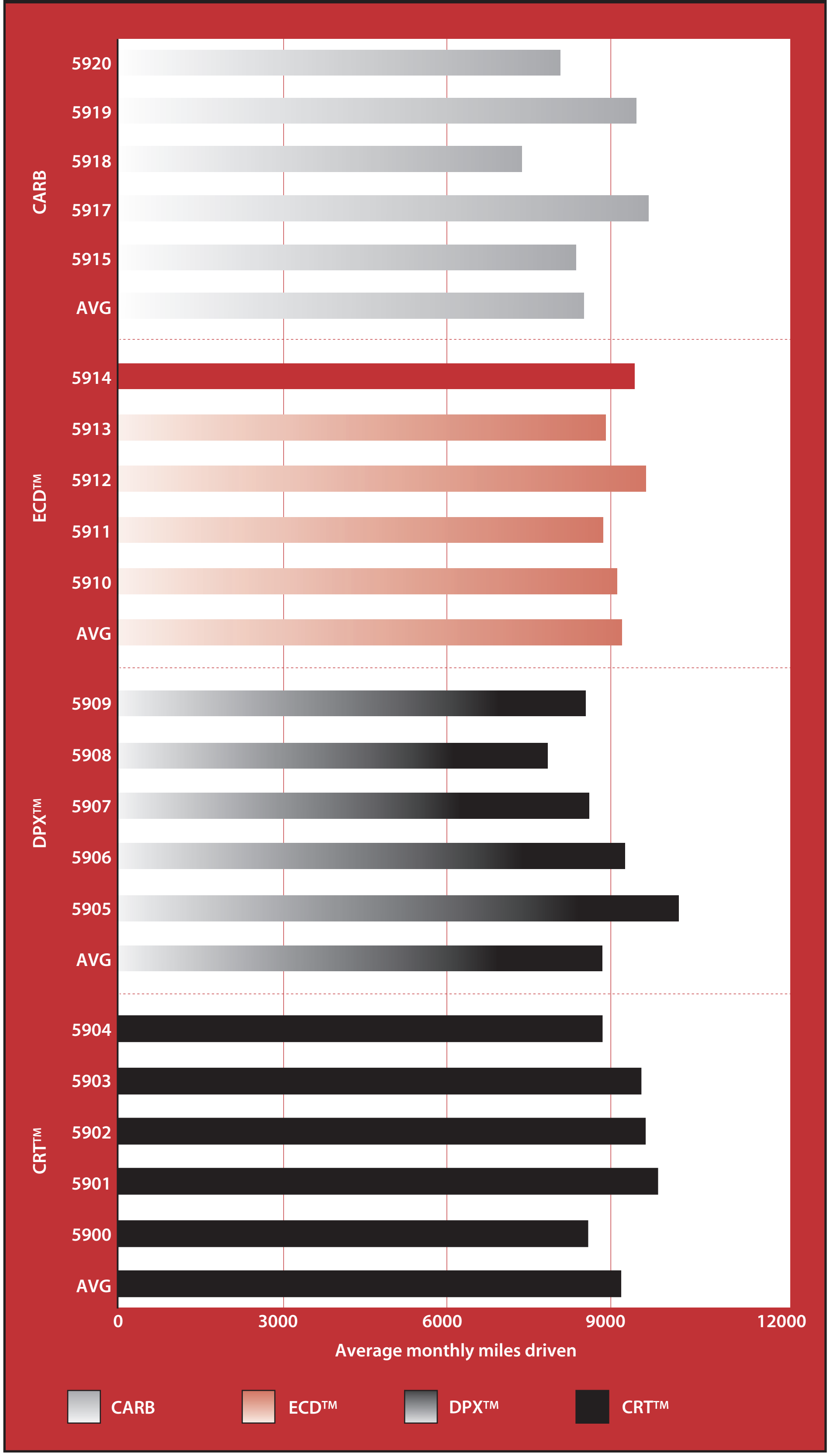
Fuel Consumption and Economy

Figure 11 shows per-truck and per-fleet fuel economy for the four study groups. Fuel economy calculations are based on fuel volume only, not on energy equivalent volume. The groups have similar fuel economies; the CARB group has the highest. The ECD™ and DPX™ groups showed a 2% decrease in fuel economy, and the CRT™ group showed a 3% decrease in fuel economy, compared to the CARB group. These differences are small, not statistically significant, and can reasonably be attributed to the lower energy content of the ECD™ fuel.

ARCO committed to Ralphs to cover the extra cost of the ECD™ fuel ($0.05–$0.10 per gallon, plus costs for delivery on demand for the temporary station). This retail cost differential between CARB diesel and ECD™ is expected to remain in effect for the foreseeable future.

For this evaluation, ARCO charged Ralphs the same price for both fuels. The average per-gallon cost to Ralphs for both fuels was $1.53. Monthly average fuel costs were $1.33–$1.79 per gallon. Each truck consumed 1,300–1,400 gallons of fuel per month. The CARB group had a fuel cost of $0.229 per mile; the ECD™

Figure 9. Average miles driven per month, by truck and fleet



group had $0.233 per mile; the DPX™ group had $0.234 per mile; and the CRT™ group $0.236 per mile. These values are comparable.

Engine Oil Consumption and Cost

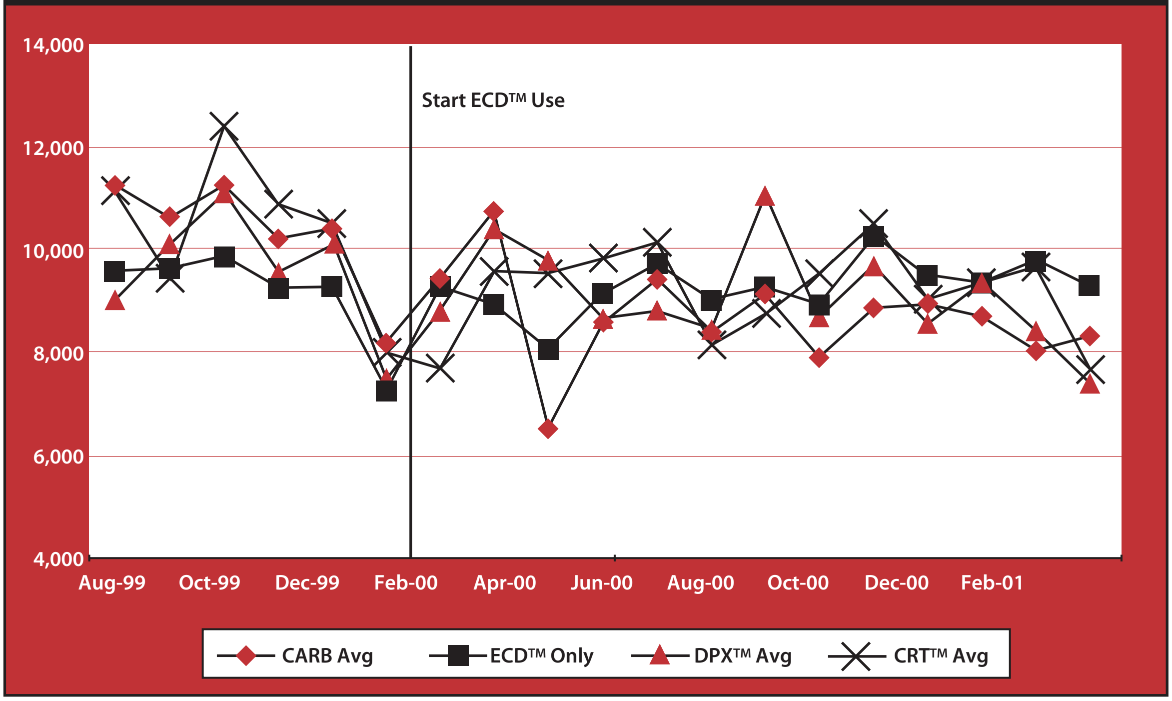
All four study groups consumed 0.0002–0.0003 quarts of engine oil per mile. These are low levels, and with oil costing $0.85 per quart, the oil consumption costs are much lower than the fuel and maintenance costs.

Low engine oil consumption rates are important for the DPF expected life. Burned engine oil has a high ash content that collects in the filter, leading to dragging of the filter (at which point the filter needs to be serviced). The higher the engine oil consumption rate, the more ash is collected in the filter, and the sooner the filter will need to be serviced. Low engine oil consumption should maximize the time between filter cleanings.

Factors Affecting Maintenance Costs

During the evaluation, the Engelhard and Johnson Matthey DPFs were not serviced at 60,000 miles (as recommended by the filter manufacturer) because they were being monitored for excessive backpressure. Ultimately, the filters operated satisfactorily on each retrofitted truck for more than 150,000 miles without servicing. This extended service interval was used to study the effect on fuel economy and engine operation. Excessive backpressure on the engine can cause lower fuel economy and possibly automatic shutdown or a reduced power

Figure 10. Monthly average mileage



engine mode.

In the Ralphs truck operation, the extended filter service period appeared to have no impact on maintenance costs. However, the cost of servicing the filters was not incurred during the evaluation.

Two to four hours are required to disassemble, clean, and reassemble the filter, ensuring the filter is flipped the opposite direction. This includes an allowance for some maintenance of the securing equipment and clamps. The most economical method for servicing and cleaning the DPFs (in-house or outsourced) has yet to be determined.

Maintenance Costs by Vehicle System

Figure 12 shows the proportions of maintenance costs related to each major truck system. The top three cost categories are similar for all four groups: (1) PMA inspections; (2) Engine- and fuel-related; and (3) Tires. The maintenance costs for the top three categories represent 58%–73% of the total maintenance costs for each group.

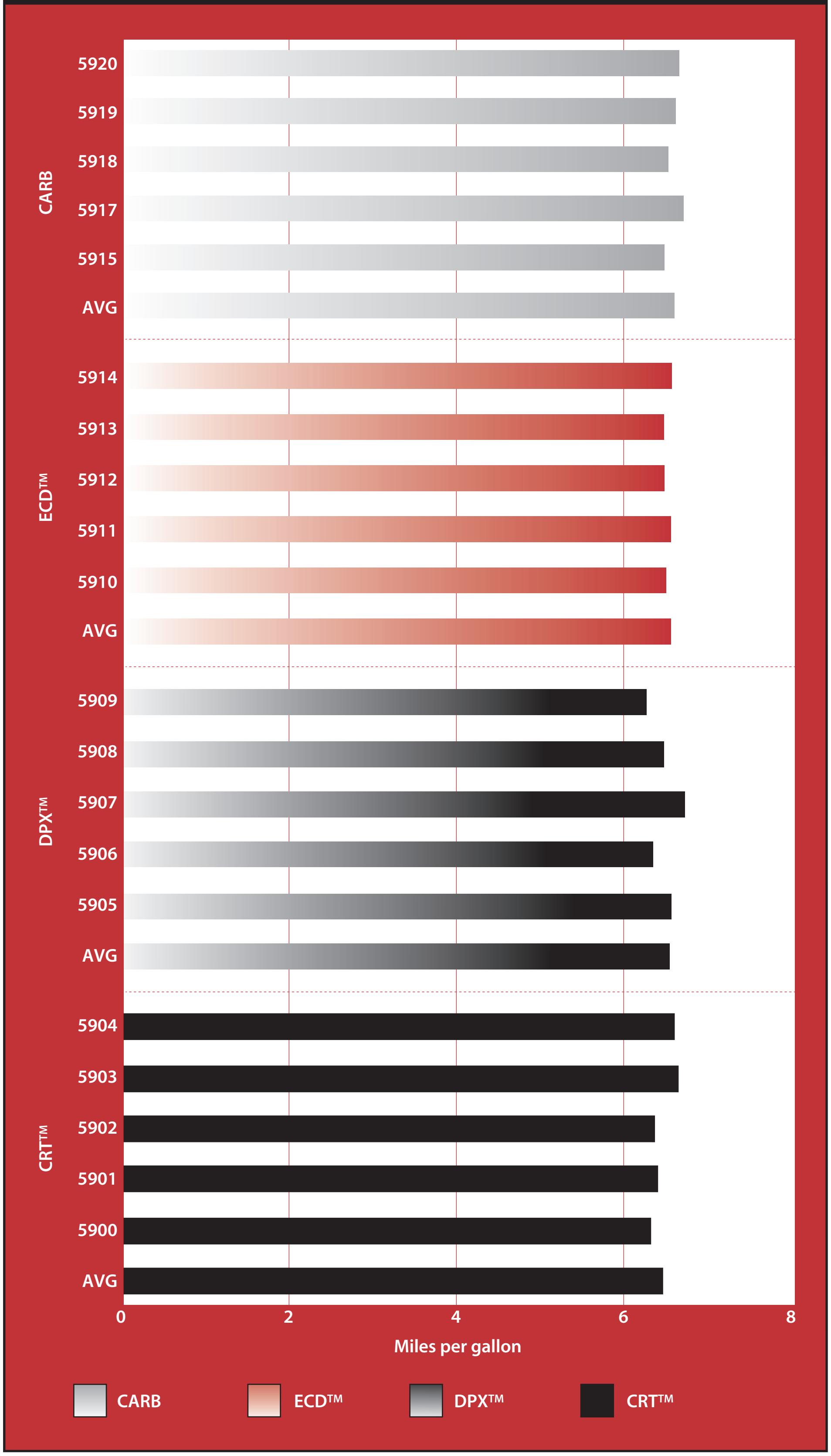
The specific contributors to these system cost categories are

- **PMA inspections** – Include only labor hours for inspections. The maintenance costs for all four groups were similar.
- **Total engine- and fuel-related systems** – Costs were similar

Table 2. Fuel properties

Property	Test Method	First-Round Testing ECDTM	First-Round Testing CARB	Second-Round Testing ECDTM	Second-Round Testing ECD-1	Second-Round Testing CARB
Sulfur, ppmw	ASTM D5453	7.4	121.1	4.1	12.7	114.5
Total Aromatics, % mass	ASTM D5186	10.9	22.5	7.7	17.5	16.1
Natural Cetane Number	ASTM D613	63.4	54.1	65.3	51.9	51.4
API Gravity, °API	ASTM D287	42.8	36.0	42.5	39.2	36.0
Density, g/ml @ 15°C	ASTM D4052	0.8119	0.8445	0.8120	0.8286	0.8437
Gross Heat of Combustion, Btu/lb	ASTM D240	19958	19665	19964	19,720	19626
Net Heat of Combustion, Btu/lb	ASTM D240	18641	18439	18649	18,468	18383
Cloud Point Deg, °C	ASTM D2500	-3	-9	-1	-11	-12
Net Heat of Combustion, Btu/Gallon	Calculated	126,302	129,945	126,356	127,703	129,432
ECDTM/CARB (for each round)	Percent (%) Difference	-2.8	0	-2.4	-1.3	0

Figure 11. Fuel economy per truck



for all groups. The ECD™ and CRT™ groups had higher costs, caused mostly by charging and cranking system repairs.

- **Exhaust system** – Costs were low for all groups. However, the DPX™ and CRT™ groups had higher costs because of some maintenance work on the exhaust stacks and checking the filters and clamps. The CRT retrofitted trucks had some cracking on the collar of the unit caused by flexing on the stack. This is most likely due to the way the support strut was attached to the exhaust stack.

- **Fuel system** – Costs for the three ECD™-fueled truck groups were similar, but the CARB group had significantly lower costs. The cost difference for the ECD™-fueled truck groups was caused by problems with a fuel return line from the cylinder head back to the fuel filter. The fuel lines were replaced after fuel started to seep from the end closest to the engine cylinder head.

  This fuel line has been a problem for other trucks at Ralphs and may be related to the comparatively low aromatics content in the ECD™ fuel. However, it is not necessarily an ECD™ fuel issue.

- **Engine system** – Costs were similar for all groups. The CARB group had the highest costs. The extra cost for the CARB group was caused by replacing an oil sensor and a turbo boost sensor.

- **Non-lighting electrical systems** – Costs for the charging and cranking systems were high for many trucks. A total of 61 batteries, 17 alternators, and 3 starters were replaced. These repairs resulted in 13 of 23 road calls.

The ECD™ and CRT™ groups had more problems with the cranking and charging systems than the other two, but they appear to have no link to the ECD™ fuel or to the DPFs.

- **Air intake and cooling systems** – Costs were similar and low for all groups.
- **Tire system** – Costs were nearly the same for three of the groups. The DPX™ group had lower costs because fewer tires were replaced.
- **Frame, steering, and suspension systems** – Costs were similar for three groups. Most were related to replacing suspension pins and bushings. The CRT™ group had no pins or bushings replaced.
- **Cab, body, and accessories systems** – Costs were about the same for three groups. The ECD™ group had higher costs than the other three because of an accident involving Truck 5911.
- **Brake system** – Costs were similar for all groups.
- **Other maintenance** – Costs included those for axle, wheel, and drive shaft systems; transmission and clutch systems; heating, ventilation, and air conditioning systems; fifth wheel system; and lighting system. The maintenance costs were low and were nearly the same for all groups.

Warranty Costs and Road Calls

Repairs covered under warranty were minor for all trucks. A few were covered on air conditioning, lighting, exhaust, and cooling systems. Total costs were $680.21 for parts and 2.64 hours of labor, and were not included in the analyses.

A road call is an on-road failure that requires an in-service truck to be towed and/or a replacement truck to be dispatched to finish the route. Only 23 road calls occurred during the evaluation period. Thirteen were caused by the cranking or charging system and required either towing to the Riverside facility or providing a jump start in the field. Two were caused by the return fuel line from the head to the fuel filter starting to seep fuel near the head. These repairs do not appear to have a direct link to the DPF systems.

Overall Maintenance Costs

Maintenance costs were affected by a series of property damage accidents unrelated to the fuel and exhaust filter systems. Of about $8,200 in costs incurred for body and frame repair following accidents, only $920 was spent for repairs to a CARB diesel truck; all other costs were for ECD™, DPX™, and CRT™ trucks.

This coincidence skews the results. For example, truck 5911 had the highest body and frame repair costs, at $4,480.71, and happened to be in the ECD™-only group.

An analysis was performed to adjust for the imbalance in accident repair costs, and for costs related to non-lighting electrical repair, which likewise happened more often on the ECD™ and DPF study trucks than on the CARB diesel trucks. Appendix A shows how the adjustments were made in an attempt to standardize them across the groups. These adjusted costs are reported here with the actual costs.

Figure 12. Share of maintenance costs across major systems

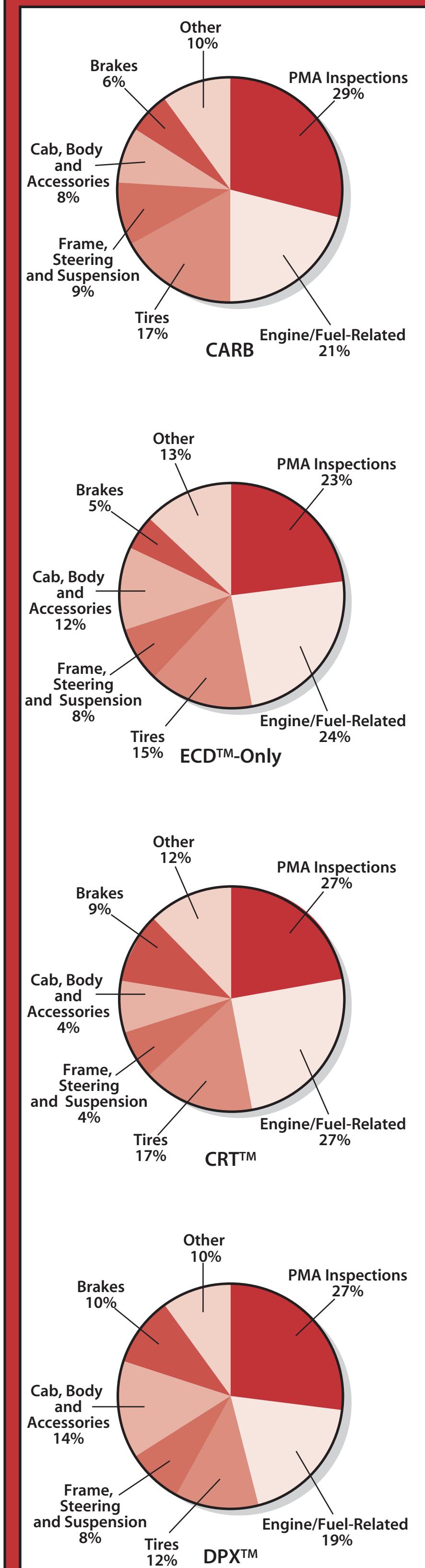


Figure 13. Total average maintenance cost per truck

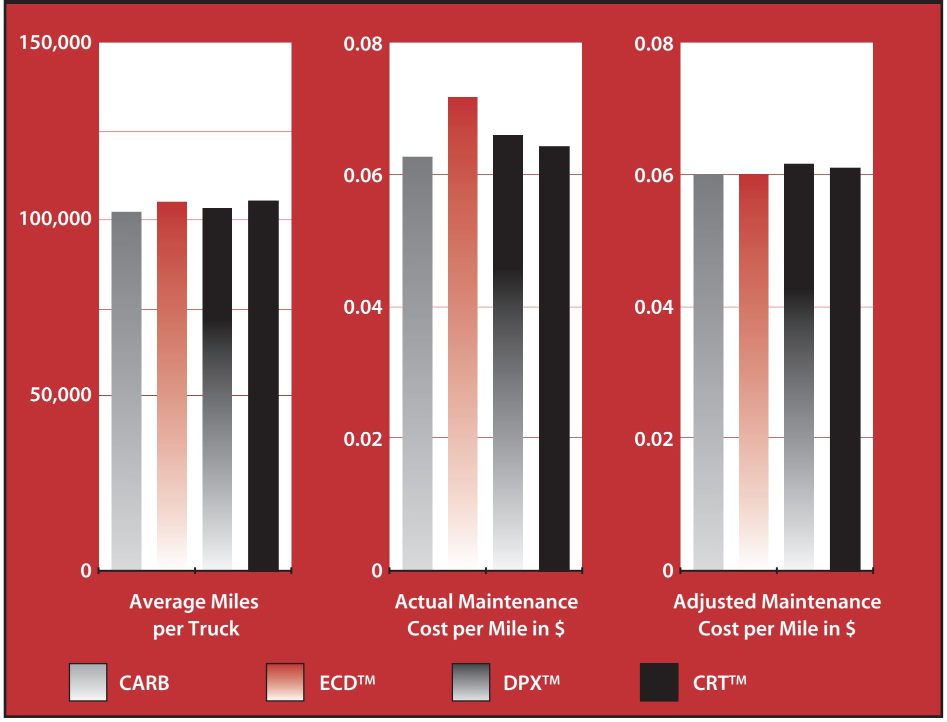


Figure 14. Total operating costs per mile in $

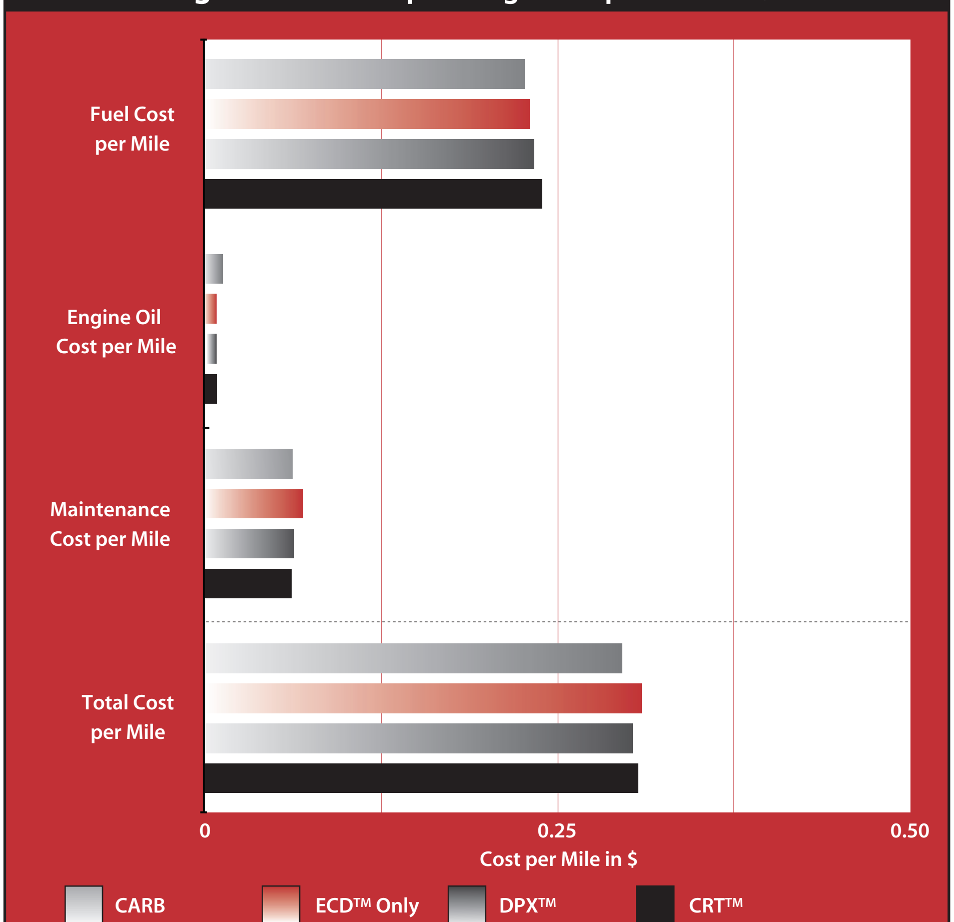


Figure 13 shows the total actual and adjusted maintenance costs by study group based on mileage, and averaged across all the trucks in each group. The figure shows that maintenance costs are comparable across the four groups.

Overall Operating Costs

Figures 14 and 15 show the overall operating costs (without driver labor) based on vehicle mileage, using the actual and adjusted maintenance costs, respectively. Taken as groups, the trucks appear to be close, on average, with operating costs of $0.293–$0.307 per mile. The ECD™ group had costs 4.8% higher, the DPX™ group 3.4% higher, and the CRT™ group 4.1% higher than the CARB group. The fuel costs do not include the incremental cost of the ECD™ fuel, reported to be $0.05–$0.10 per gallon.

As discussed earlier, three maintenance cost categories were significantly higher for several trucks, from causes unrelated to the fuel or DPFs. A separate analysis was conducted in which the body, frame, and non-lighting electrical systems maintenance costs were removed from all four groups and replaced with standardized or consistent maintenance costs to remove the effect of randomness.

Using the revised maintenance costs, the comparisons of the ECD™-fueled truck groups with the CARB group differ slightly. Total operating costs for the ECD™ group were 1.4% higher than for the CARB group, for the DPX™ group 2.8% higher, and for the CRT™ group 3.8% higher.

Emission Testing Results

Emission tests were conducted on all 20 trucks at the Ralphs Service Center in Riverside, California (Figure 16), using WVU's portable chassis dynamometer.

The vehicle exhaust was ducted to a full-scale dilution tunnel, and the diluted exhaust was analyzed using nondispersive infrared analyzers for CO and CO_2. Chemiluminescent detection was used for NO_x. Hydrocarbons (HC) were analyzed using flame ionization detection (FID). The FID analyzer was calibrated using propane.

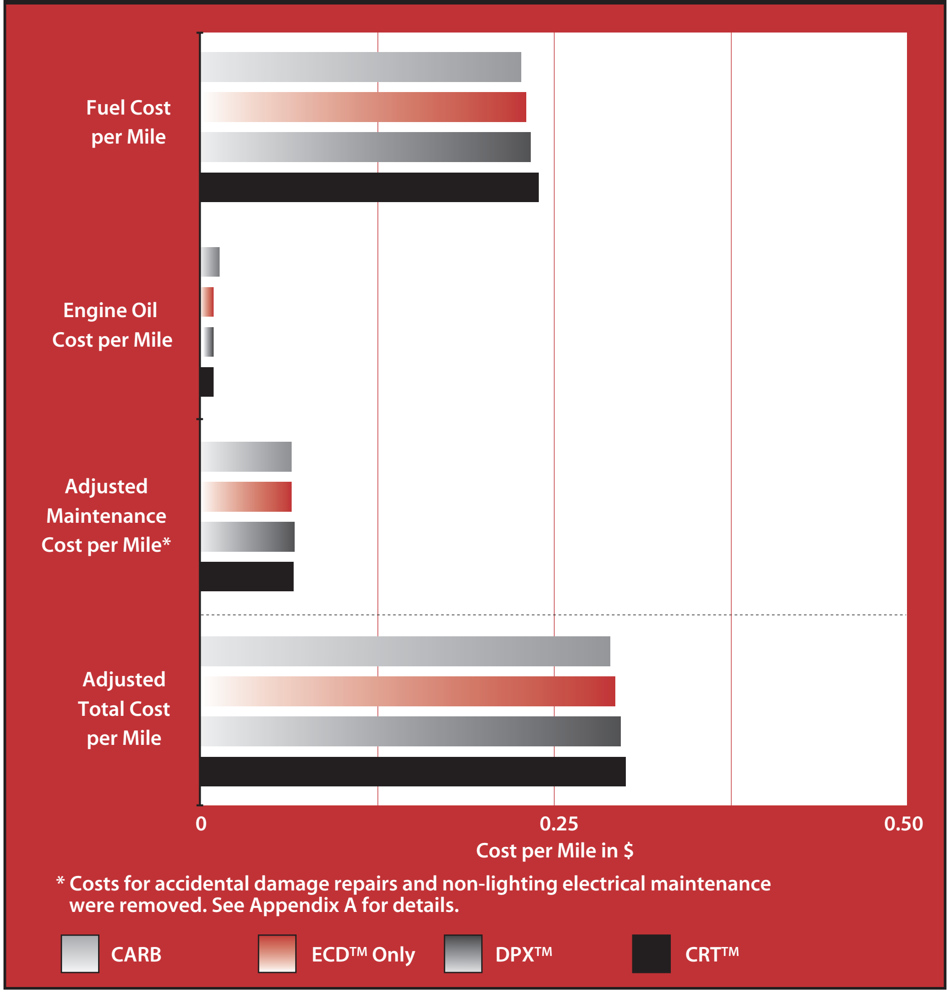
The gaseous emission data were available as continuous concentrations throughout each test, and the product of concentration and tunnel flow were integrated to yield an ultimate emission value in grams per mile (g/mi). PM emissions were collected from the dilute exhaust flow on 70-mm filters. Fuel economies were determined using a carbon balance and exhaust emission data.

Testing Cycles and Testing Rounds

Two driving schedules were used to exercise the trucks through emission characterization. The 5-mile route consists of 5 "peaks," each composed of acceleration, cruise, and deceleration sections, with idle sections between the peaks (Figure 17). This route explores full-power operation during part of the test schedule and elicits realistic PM production from the engine, since full-power diesel engine operation is usually determined by the smoke limit.

The other test cycle schedule was the City Suburban Heavy Vehicle

Figure 15. Total adjusted operating costs per mile in $



* Costs for accidental damage repairs and non-lighting electrical maintenance were removed. See Appendix A for details.

Figure 16. Emission testing of one Ralphs truck

Figure 17. Two 5-mile route cycles for Ralphs truck 5905

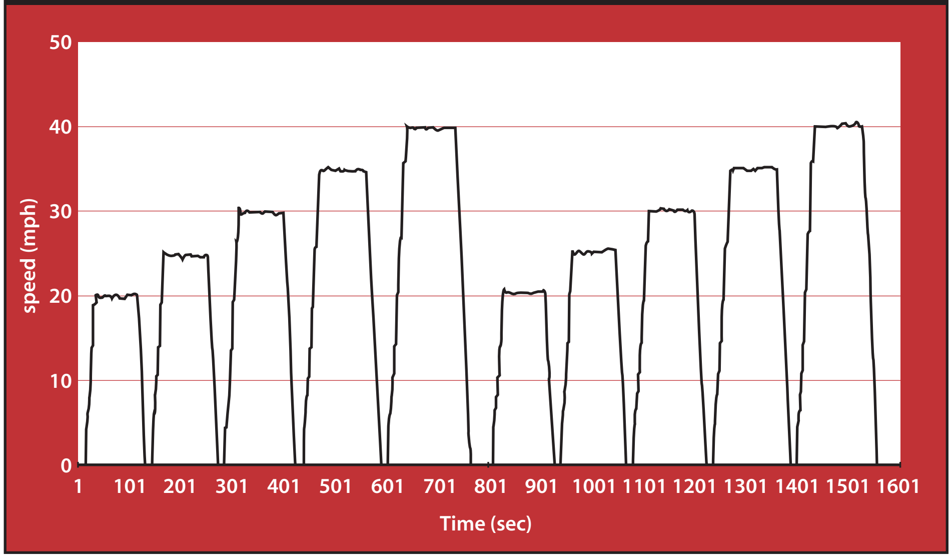
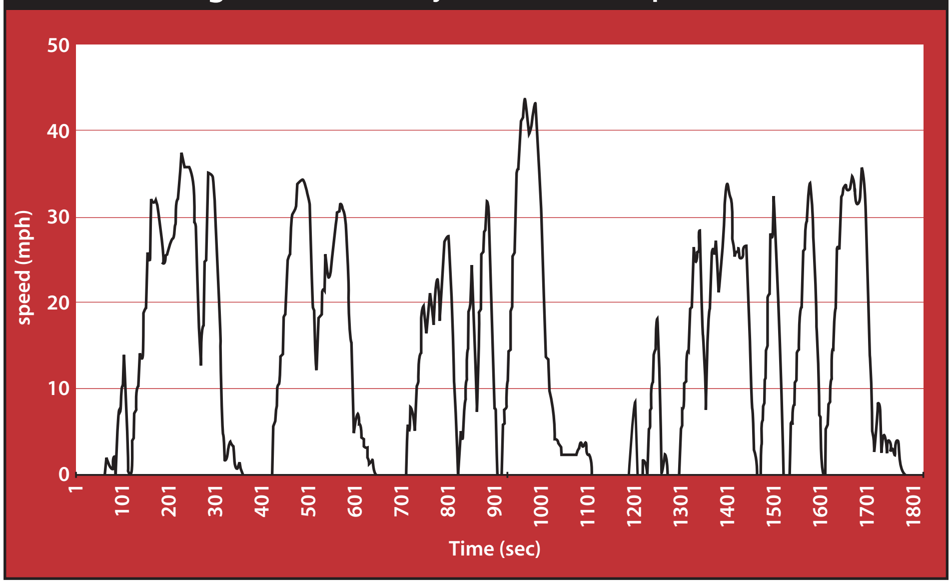


Figure 18. CSHVR cycle on one of Ralphs trucks



Route (CSHVR), which was derived from real-world tractor-trailer activity. The cycle replicates a route of 6.72 miles (Figure 18). The emission results from the CSHVR test cycle are emphasized in this report. Detailed emission test results from both cycles and both testing rounds are presented in Appendix B and in *Ralphs Grocery EC-Diesel™ Truck Fleet Final Data Report*. A summary of results from the 5-mile route is presented on page 21.

Emissions were very low in some tests, requiring that the same cycle be repeated to produce enough PM and HC emissions to be measured accurately. Figure 17 illustrates one such double-length emission test cycle. Per-mile and standard length emission test results are reported.

Two rounds of emission testing were conducted approximately 1 year apart. The first was completed January through March 2000; the second March through April 2001. All 20 trucks were tested in each round.

Results of the CSHVR Cycle

Figures 18 through 24 show results for each group and test cycle for rounds 1 and 2.

The DPFs accumulated on average 115,000–120,000 miles between the two rounds with no servicing or cleaning of the filters. Most results shown here are averaged over five trucks for each truck group, and each truck's emission testing results are based on the average of several test runs per truck.

The PM results for the CARB group increased significantly between rounds. The DPF retrofitted groups

(DPX™ and CRT™) had very low PM results: 97%–99% lower than the CARB group, even in round 2 after 120,000 miles of operation.

The HC results were about the same for the CARB and ECD™ groups for both rounds. The ECD™ group had slightly higher results (0.356 g/mi) in the second round than in the first round (0.256 g/mi). The DPF retrofitted trucks had extremely low HC emissions that were at or below the detection limit of the analytical equipment.

The CO emission results for all groups increased significantly for round 2. However, the DPF retrofitted trucks had significantly lower CO emissions than the CARB group for both rounds.

In the first round, there was a 15%–20% reduction in NO_x emissions for the ECD™ and DPF groups. However, there was no reduction in the second round. The ECD™ and filter retrofitted truck groups showed a 10% reduction for the DPX™ group, a 4% increase for the CRT™ group, and a 9% increase for the ECD™ group. These results indicate no major effect on NO_x.

The results for both rounds show a consistent, slight reduction of CO_2 for the ECD™ and DPF truck groups. The results changed very little between rounds.

In comparing fuel economy as part of emission testing, the different energy content of the CARB diesel and ECD™ is taken into account. The results for the fuel economy are calculated based on a carbon balance of the emissions and are represented in the figure as miles per equivalent gallon. Fuel economy was slightly lower for the

Figure 19. PM emissions from both rounds on the CSHVR cycle

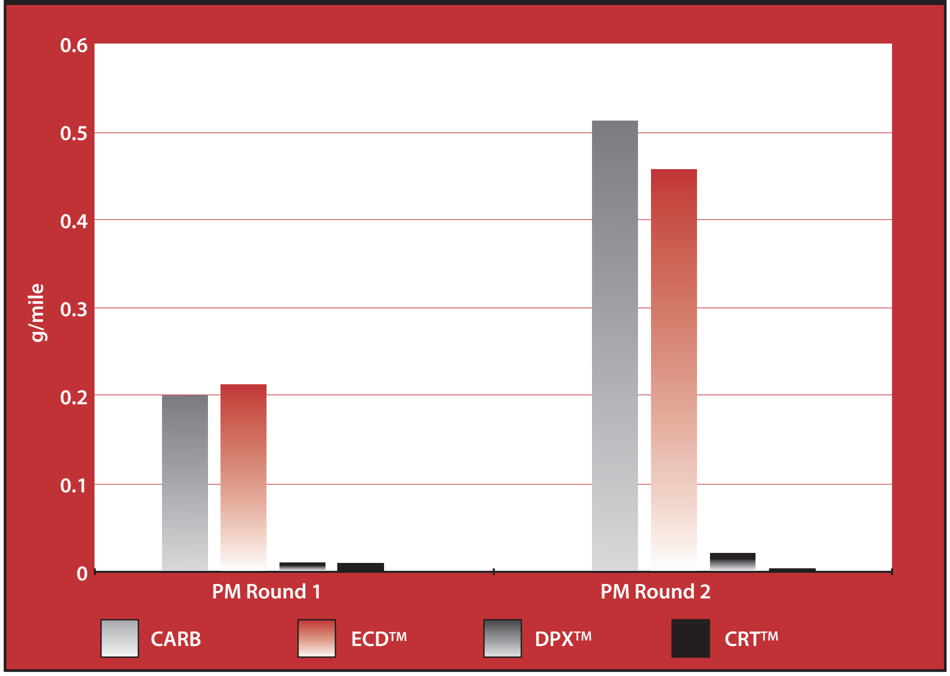


Figure 20. HC emissions from both rounds on the CSHVR cycle

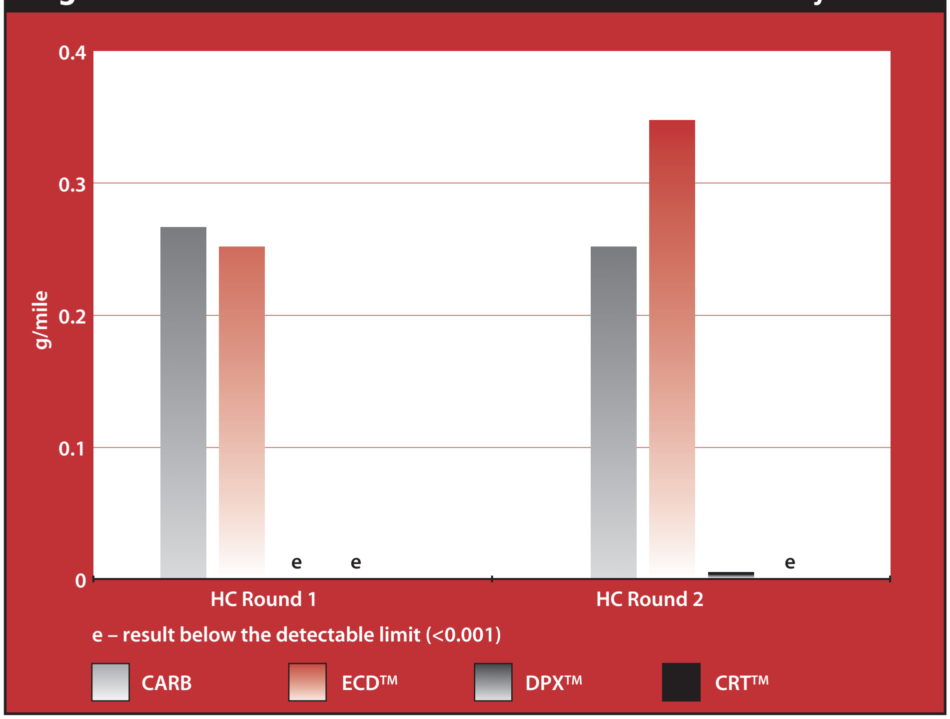


Figure 21. CO emissions from both rounds on the CSHVR cycle

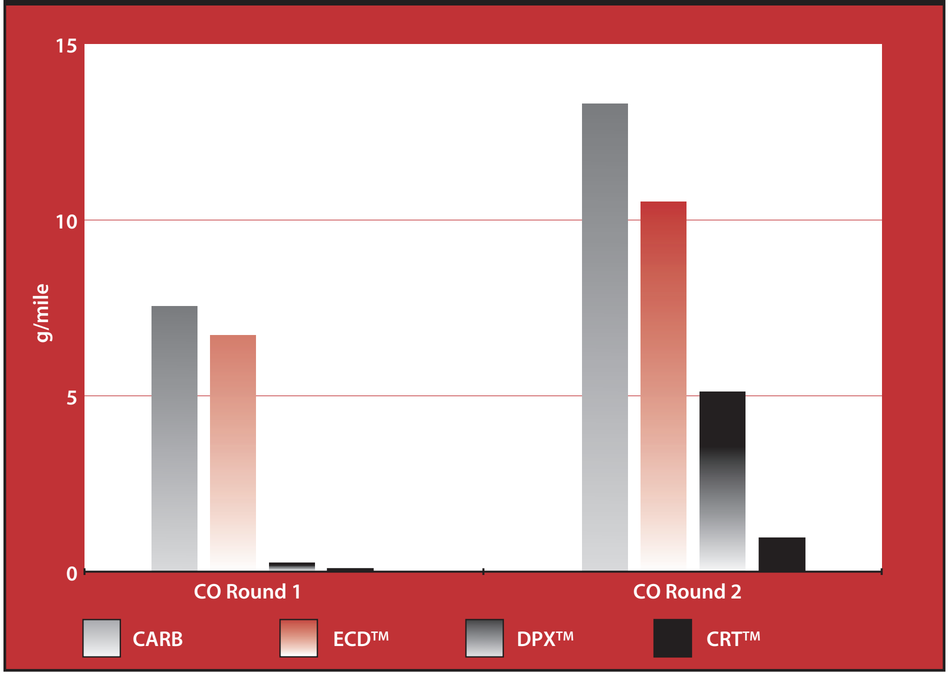
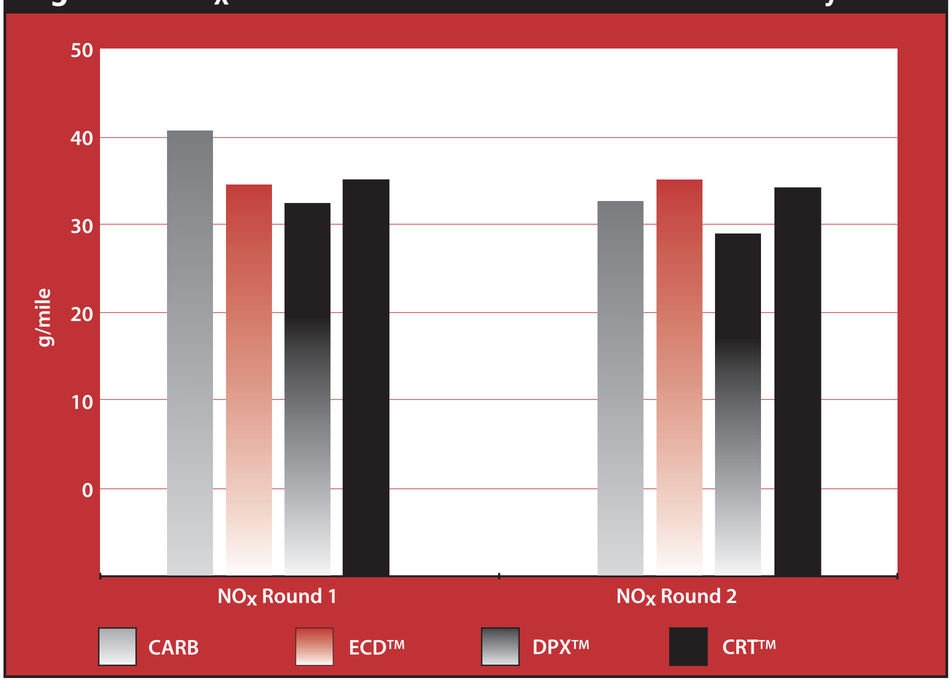


Figure 22. NO_X emissions from both rounds on the CSHVR cycle



ECD™, DPX™, and CRT™ groups. The results show that the fuel economy is about the same for the CARB and ECD™ groups, with a 2% lower result for the ECD™ group in the second round.

The two DPF groups were 2% higher in miles per equivalent gallon than the CARB group in the first round, and 1%–4% higher in the second round. These results indicate no fuel economy impact with DPF retrofits.

Summary Results for the 5-Mile Cycle

Figure 25 shows the results from the second round on the 5-mile test cycle. (For ease of presentation across species, some emission values were divided by multiples of 10.) Compared with the CARB diesel fuel, the ECD™ fuel with the DPX™ filter resulted in 98% reductions in HC and PM, a 65% reduction in CO, and a 15% reduction in NO_x. Trucks using the same ECD™ fuel with the CRT™ filter emitted 99% less HC, 98% less PM, 90% less CO, and 15% less NO_x. As with the CSHVR cycle, the filters had very little impact on fuel economy.

Special Emission Test

To evaluate fuel and filter effects while using the same truck and engine, special emission tests were run on trucks 5903 and 5904. Figure 26 shows comparisons between CARB diesel and ECD-1 fuels, and between the same truck with no filter and with the CRT™ filter.

This report focuses on results from the second round. The tests consisted of:

- CARB diesel fuel and no filter
- ECD-1 fuel and no filter
- ECD-1 and CRT filter

ECD-1 was tested in round 2 because it is a commercially available ULSD fuel. ECD-1 differs slightly from ECD™ in that the aromatics content is higher (nearly the same as the CARB fuel) and the sulfur level is below 15 ppm, but not as low as the ECD™ fuel (less than 7 ppm). Table 2 shows the differences among the three types of diesel fuel.

Figure 26 shows the average results for the two trucks from the special emissions testing. Compared with the CARB diesel, the ECD-1 fuel alone (without DPF) caused an 11% decrease in HC emissions, an 8% decrease in PM and NO_x, and a 7% decrease in CO. Combining the ECD-1 fuel and the CRT™ filter decreased HC and PM by 98% and CO by 78%. These results are similar to those from the ECD™ fuel testing.

Figure 23. CO_2 emissions from both rounds on the CSHVR cycle

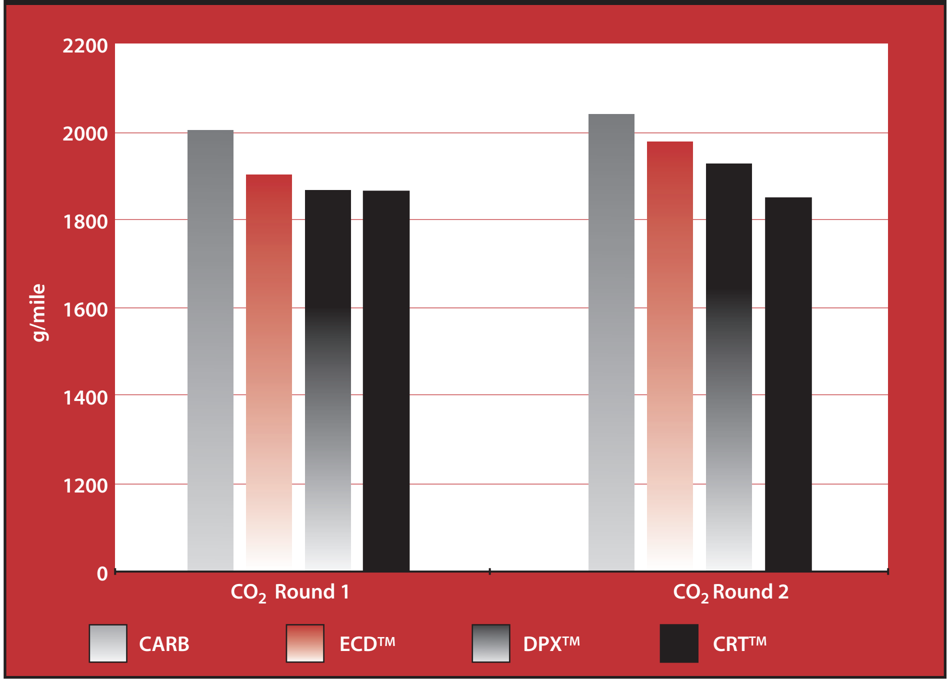


Figure 24. MPG (fuel economy) from both rounds on the CSHVR cycle

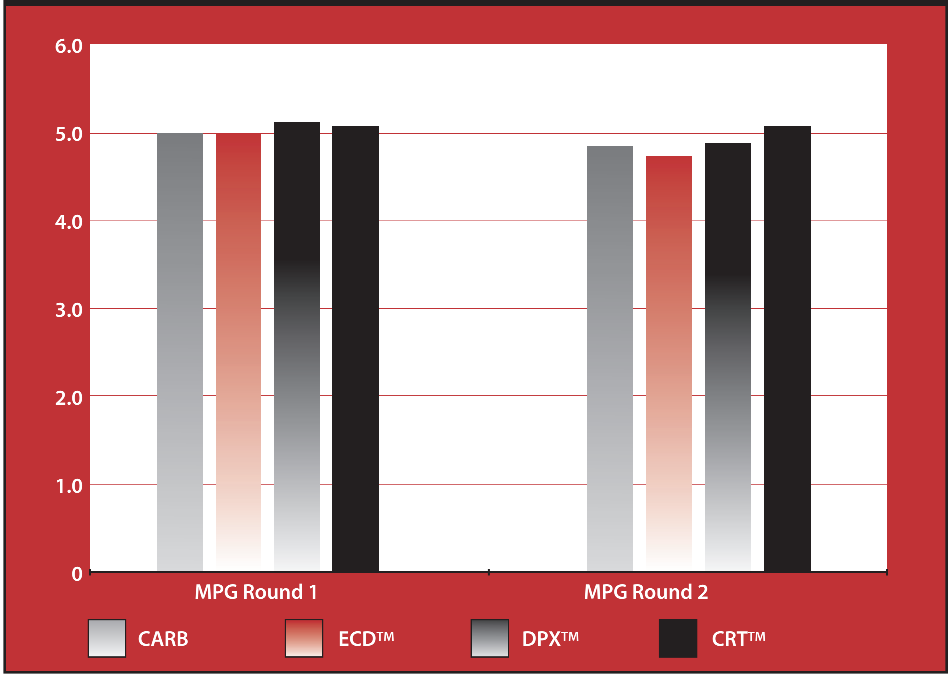


Figure 25. Emission results for 5-mile cycle, second round only

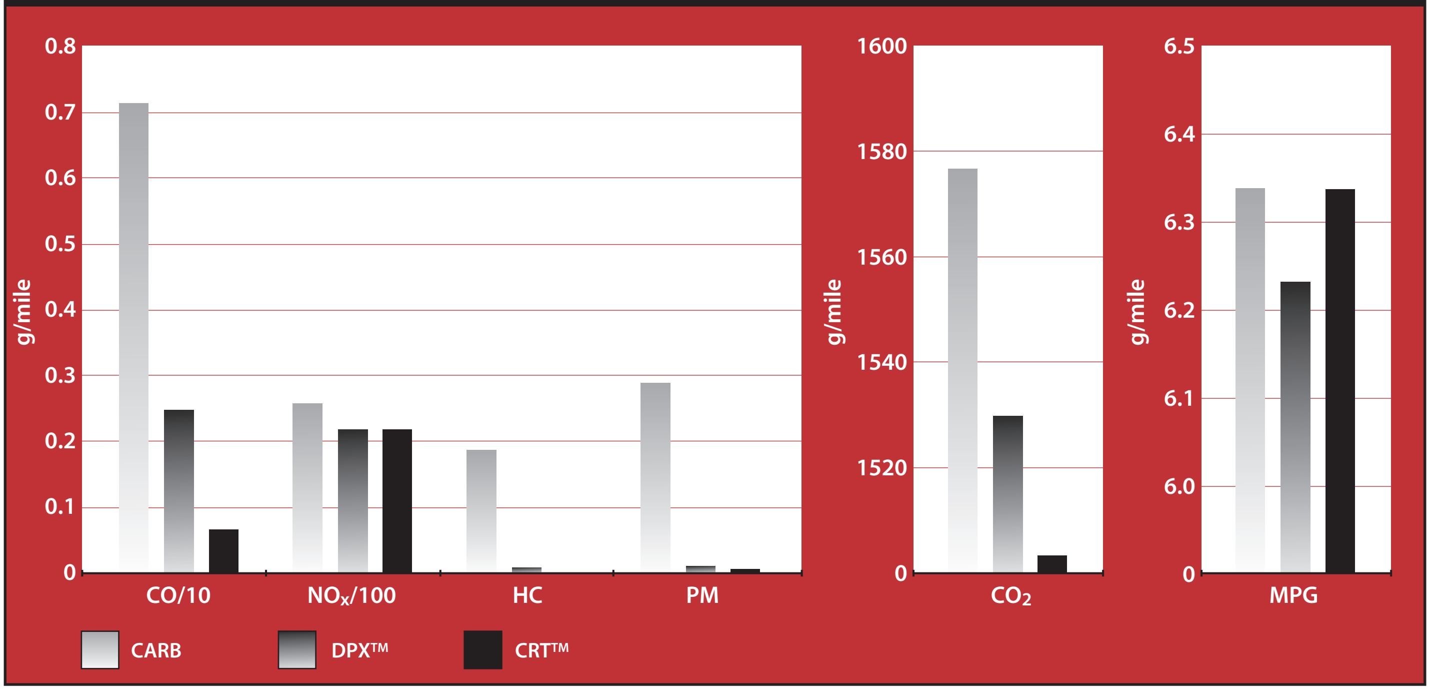
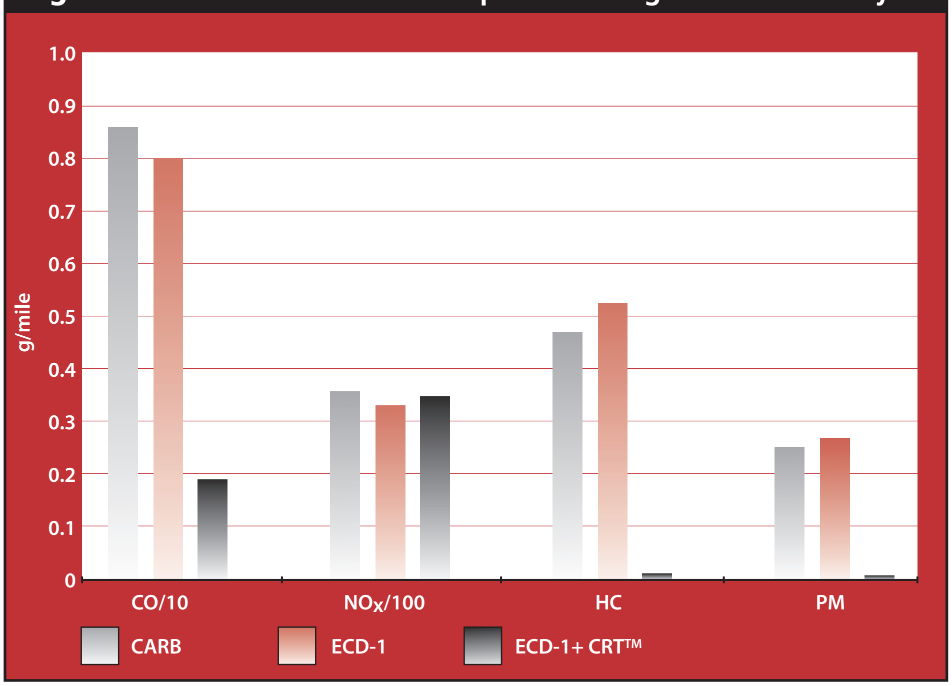


Figure 26. Emission results from special testing on the CSHVR cycle



Summary and Conclusions

Based on the evaluation of Ralphs Grocery Company ECD™ trucks used in the Los Angeles area, we conclude the following major points, related to start-up issues, 12-month testing in service, and emission testing on the portable chassis dynamometer.

Start-Up Issues

- Users of passive regenerative catalyzed DPFs must service the filters. On-board monitoring of backpressure may help protect the filter and the engine.
- Understanding the duty cycle to which the filter will be exposed is critical for proper operation and for determining service intervals. To clean their own filters, users may need special equipment for handling the material removed from the filter.
- The filters are generally intended to replace the mufflers and are larger and heavier than most OEM mufflers. Therefore, engineering is required to properly install and support the filters for a specific truck and engine model. An experienced service company should install the filters.
- A local engine dealership easily installed the filters. The cost of the filters and installation was estimated to be about $6,000 per truck. No changes were required for the facilities at Ralphs other than the temporary bulk fuel storage tank.
- Ensuring that only ECD™ fuel was used for the filter retrofitted trucks was important for this test and for the proper operation of the DPFs. The use of higher sulfur diesel fuel (>50 ppm sulfur) does not permanently damage the filters, but temporarily reduces the effectiveness of the catalyst.

In-Service 12-Month Evaluation

- Trucks that were equipped with passive regenerative catalyzed DPFs and fueled by ECD™ operated reliably for more than 100,000 miles with no filter-related issues that required the trucks to be taken out of service.
- All test trucks were operated in essentially the same duty cycle and had average monthly mileage per truck of 7,300–10,104 miles.
- The fuel economy result does not indicate a fuel economy penalty for using DPFs in this application. Volumetric fuel economy for the ECD™ group and the retrofitted truck groups was 2%–3% lower than that of the CARB group. The ECD™ fuel had an energy content 2.45–2.8% lower than a typical CARB diesel fuel. Therefore, the in-service fuel economy results were consistent with the lower energy content of the fuel used.
- In general, engine oil consumption was low for all trucks, which was key to extending the service interval of the DPFs 150,000 miles. (The recommended filter service interval is 60,000 miles or 12 months.)

- The use of passive regenerative catalyzed DPFs and ULSD fuel caused the maintenance costs to increase by 3%–4% to maintain the filter system. This increase was related to securing the exhaust stack. More engineering on installing and securing the filters may significantly reduce this extra cost.
- Excluding the non-lighting electrical system maintenance costs, the engine- and fuel-related maintenance costs were slightly higher for the ECD™ and retrofitted vehicles compared to the CARB group. This was caused by exhaust system maintenance, specifically the clamps for the filters. Some extra maintenance was also required for a fuel return hose failure on 12 of the 15 ECD™-fueled trucks. No costs for servicing the DPFs (estimated at 2–4 labor hours) were incurred.
- The overall per-mile operating cost showed a 3%–4% higher cost for operating the ECD™ and retrofitted trucks compared to the CARB group. The extra cost was related to repairing and securing the filters and to differences in fuel energy content. The fuel cost used in this analysis, however, did not include the $0.05–$0.10 increased cost per gallon for the ECD™ fuel, which was paid for by ARCO.

Emission Testing

- The retrofitted trucks using ULSD fuel had significantly lower PM, HC, and CO emissions. Many readings were at or below the detection limit of the measuring equipment. The CO results varied depending on the test cycle, and underwent some change over time. The NO_x emissions trended lower with some variability. The CO_2 emissions were variable, but about the same overall compared to the CARB results. The fuel economy values as measured during emission testing were about the same.
- All 20 trucks operated about 150,000 miles between the two rounds of emission testing. None of the 10 retrofitted trucks had the filters cleaned or serviced. Some variation and degradation (increasing between the two rounds) in the emission control results were observed. However, the retrofitted trucks continued to see much lower emissions of PM and HC.
- Special emission testing was performed on two trucks, in which the fuel and filter combinations were varied on the same truck. Changing from CARB diesel to ECD™ with no exhaust filter yielded PM results that were variable from round to round. The HC, CO, and NO_x were reduced by 13%–18%, CO_2 was reduced 6%–4%, and the energy equivalent fuel economy was about the same.
- Emission tests in which ECD™ and commercially available ECD-1 fuel were compared, showed that the CO, NO_x, and CO_2 were slightly lower, the HC and PM were slightly higher, and the fuel economy was slightly higher with the ECD™ fuel.
- Emission tests in which ECD-1 fuel was used and a CRT™ filter was installed, compared to CARB diesel operation, showed lower emissions: PM (94%–>99% less); CO (44%–97% less); NO_x (13%–24% less). CO_2 emissions were 9% lower to 1% greater, and fuel economy was 5% lower to 5% greater.

Future ECD™ Operation at Ralphs

BP now offers a commercial ULSD fuel, called ECD-1, in California. The major difference between ECD™ and ECD-1 is that the ECD-1 fuel has a higher aromatics content than the ECD™. Ralphs converted the filter-equipped trucks to using ECD-1 in July 2001. Nine of the 10 DPF retrofitted trucks have operated 140,000–180,000 miles without having the filters cleaned. Ralphs continues to investigate and search for funding to convert the entire fleet of diesel trucks at the Riverside Service Center to ECD-1 and DPFs.

At the time of this writing, Ralphs continues to use ECD-1 and the DPFs.

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Appendix A

Fleet Summary Statistics

Ralphs Grocery Company (Riverside, CA) Fleet Summary Statistics

Fleet Operations and Economics

	CARB Diesel	ECD™ ECD™ Only	ECD™ Engelhard	ECD™ JMI
Number of Vehicles	5	5	5	5
Period Used for Fuel and Oil Op Anaysis Total Number of Months in Period Fuel and Oil Analysis Base Fleet Mileage	3/00-2/01 12 516,246	3/00-2/01 12 554,393	3/00-2/01 12 535,685	3/00-2/01 12 552,352
Period Used for Maintenance Op Analysis Total Number of Months in Period Maintenance Analysis Base Fleet Mileage	3/00-2/01 12 516,246	3/00-2/01 12 554,393	3/00-2/01 12 535,685	3/00-2/01 12 556,979
Average Monthly Mileage per Vehicle Fleet Fuel Usage in Gallon	8,604 77,340	9,240 84,458	8,928 82,021	9,283 85,343
Representative Fleet MPG (energy equiv) Ratio of MPG (AF/DC)	6.68	6.56 0.98	6.53 0.98	6.47 0.97
Average Fuel Cost as Reported (with tax) Average Fuel Cost per Energy Equivalent Fuel Cost per Mile	1.53 per Gal D2 1.53 0.229	1.53 per Gal D2 1.53 0.233	1.53 per Gal D2 1.53 0.234	1.53 per Gal D2 1.53 0.236
Number of Make-Up Oil Quarts per Mile Oil Cost per Quart Oil Cost per Mile	0.0003 0.85 0.0003	0.0002 0.85 0.0002	0.0002 0.85 0.0002	0.0002 0.85 0.0002
Total Scheduled Repair Cost per Mile Total Unscheduled Repair Cost per Mile Total Maintenance Cost per Mile	0.022 0.042 0.064	0.021 0.053 0.074	0.022 0.046 0.068	0.022 0.045 0.066
Total Operating Cost per Mile	**0.293**	**0.307**	**0.303**	**0.303**

Maintenance Costs

	CARB Diesel	ECD™ ECD™ Only	ECD™ Engelhard	ECD™ JMI
Fleet Mileage	516,246	554,393	535,685	556,979
Total Parts Cost	10,893.99	15,781.25	11,569.52	14,262.27
Total Labor Hours	441.7	503.2	501.7	451.8
Average Labor Cost (@ $50.00 per hour)	22,082.50	25,157.50	25,082.50	22,591.00
Total Maintenance Cost	32,976.49	40,938.75	36,652.02	36,853.27
Total Maintenance Cost per Truck	6,595.30	8,187.75	7,330.40	7,370.65
Total Maintenance Cost per Mile	**0.064**	**0.074**	**0.068**	**0.066**

Breakdown of Maintenance Costs by Vehicle System

	CARB Diesel	ECD™ ECD™ Only	ECD™ Engelhard	ECD™ JMI
Fleet Mileage	**516,246**	**554,393**	**535,685**	**556,979**
Total Engine/Fuel-Related Systems (ATA VMRS 30, 31, 32, 33, 41, 42, 43, 44, 45)				
Parts Cost	3,913.48	5,771.77	3,860.20	5,810.44
Labor Hours	59.5	85.6	64.6	91.3
Average Labor Cost	2,977.00	4,282.00	3,227.50	4,563.00
Total Cost (for system)	6,890.48	10,053.77	7,087.70	10,373.44
Total Cost (for system) per Truck	1,378.10	2,010.75	1,417.54	2,074.69
Total Cost (for system) per Mile	**0.0133**	**0.0181**	**0.0132**	**0.0186**
Exhaust System Repairs (ATA VMRS 43)				
Parts Cost	31.51	24.91	197.44	70.51
Labor Hours	6.8	6.9	17.5	26.9
Average Labor Cost	337.50	346.50	876.50	1,346.50
Total Cost (for system)	369.01	371.41	1,073.94	1,417.01
Total Cost (for system) per Truck	73.80	74.28	214.79	283.40
Total Cost (for system) per Mile	**0.0007**	**0.0007**	**0.0020**	**0.0025**
Fuel System Repairs (ATA VMRS 44)				
Parts Cost	455.34	322.75	384.39	420.39
Labor Hours	6.5	21.4	19.1	22.8
Average Labor Cost	327.00	1,071.00	953.00	1,139.00
Total Cost (for system)	782.34	1,393.75	1,337.39	1,559.39
Total Cost (for system) per Truck	156.47	278.75	267.48	311.88
Total Cost (for system) per Mile	**0.0015**	**0.0025**	**0.0025**	**0.0028**
Power Plant (Engine) Repairs (ATA VMRS 45)				
Parts Cost	1,423.68	1,343.91	1,353.55	1,424.30
Labor Hours	2.2	1.8	0.8	0.2
Average Labor Cost	111.50	90.00	38.50	10.50
Total Cost (for system)	1,535.18	1,433.91	1,392.05	1,434.80
Total Cost (for system) per Truck	307.04	286.78	278.41	286.96
Total Cost (for system) per Mile	**0.0030**	**0.0026**	**0.0026**	**0.0026**
Electrical System Repairs (ATA VMRS 30-Electrical General, 31-Charging, 32-Cranking, 33-Ignition)				
Parts Cost	1,632.64	3,574.58	1,437.69	3,485.16
Labor Hours	27.9	37.8	17.3	31.8
Average Labor Cost	1,394.50	1,887.50	864.50	1,592.00
Total Cost (for system)	3,027.14	5,462.08	2,302.19	5,077.16
Total Cost (for system) per Truck	605.43	1,092.42	460.44	1,015.43
Total Cost (for system) per Mile	**0.0059**	**0.0099**	**0.0043**	**0.0091**

Breakdown of Maintenance Costs by Vehicle System (continued)

	CARB Diesel	ECD™ ECD™ Only	ECD™ Engelhard	ECD™ JMI
Air Intake System Repairs (ATA VMRS 41)				
Parts Cost	162.97	94.60	130.10	65.75
Labor Hours	0.3	0.0	0.4	0.0
Average Labor Cost	12.50	0.00	20.00	0.00
Total Cost (for system)	175.47	94.60	150.10	65.75
Total Cost (for system) per Truck	35.09	18.92	30.02	13.15
Total Cost (for system) per Mile	**0.0003**	**0.0002**	**0.0003**	**0.0001**
Cooling System Repairs (ATA VMRS 42)				
Parts Cost	207.34	411.02	357.03	344.33
Labor Hours	15.9	17.7	9.5	9.5
Average Labor Cost	794.00	887.00	475.00	475.00
Total Cost (for system)	1,001.34	1,298.02	832.03	819.33
Total Cost (for system) per Truck	200.27	259.60	166.41	163.87
Total Cost (for system) per Mile	**0.0019**	**0.0023**	**0.0016**	**0.0015**
Brake System Repairs (ATA VMRS 13)				
Parts Cost	449.17	785.96	1,400.51	1,482.10
Labor Hours	32.5	22.1	48.3	39.6
Average Labor Cost	1,624.00	1,105.50	2,416.50	1,981.00
Total Cost (for system)	2,073.17	1,891.46	3,817.01	3,463.10
Total Cost (for system) per Truck	414.63	378.29	763.40	692.62
Total Cost (for system) per Mile	**0.0040**	**0.0034**	**0.0071**	**0.0062**
Transmission Repairs (ATA VMRS 26)				
Parts Cost	0.00	37.20	17.07	0.00
Labor Hours	1.9	6.4	3.1	2.9
Average Labor Cost	93.00	317.50	153.00	146.00
Total Cost (for system)	93.00	354.70	170.07	146.00
Total Cost (for system) per Truck	18.60	70.94	34.01	29.20
Total Cost (for system) per Mile	**0.0002**	**0.0006**	**0.0003**	**0.0003**
Clutch Repairs (ATA VMRS 23)				
Parts Cost	0.00	0.00	0.00	0.00
Labor Hours	0.3	0.0	0.4	1.7
Average Labor Cost	16.50	0.00	20.00	83.50
Total Cost (for system)	16.50	0.00	20.00	83.50
Total Cost (for system) per Truck	3.30	0.00	4.00	16.70
Total Cost (for system) per Mile	**0.0000**	**0.0000**	**0.0000**	**0.0001**

Breakdown of Maintenance Costs by Vehicle System (continued)

	CARB Diesel	ECD™ ECD™ Only	ECD™ Engelhard	ECD™ JMI
Cab, Body, and Accessories Systems Repairs (ATA VMRS 02-Cab and Sheet Metal, 50-Accessories, 71-Body)				
Parts Cost	838.12	1,484.16	1,244.26	854.85
Labor Hours	37.7	67.8	77.0	19.6
Average Labor Cost	1,885.50	3,392.00	3,849.50	980.50
Total Cost (for system)	2,723.62	4,876.16	5,093.76	1,835.35
Total Cost (for system) per Truck	544.72	975.23	1,018.75	367.07
Total Cost (for system) per Mile	**0.0053**	**0.0088**	**0.0095**	**0.0033**
Inspections Only - no parts replacements (101)				
Parts Cost	0.00	0.00	0.00	0.00
Labor Hours	190.6	190.3	196.2	197.7
Average Labor Cost	9,527.50	9,513.00	9,810.50	9,884.00
Total Cost (for system)	9,527.50	9,513.00	9,810.50	9,884.00
Total Cost (for system) per Truck	1,905.50	1,902.60	1,962.10	1,976.80
Total Cost (for system) per Mile	**0.0185**	**0.0172**	**0.0183**	**0.0177**
HVAC System Repairs (ATA VMRS 01)				
Parts Cost	515.24	483.27	255.09	634.78
Labor Hours	19.0	28.5	17.0	19.3
Average Labor Cost	951.50	1,423.00	851.00	962.50
Total Cost (for system)	1,466.74	1,906.27	1,106.09	1,597.28
Total Cost (for system) per Truck	293.35	381.25	221.22	319.46
Total Cost (for system) per Mile	**0.0028**	**0.0034**	**0.0021**	**0.0029**
Air System Repairs (ATA VMRS 10)				
Parts Cost	0.00	0.00	0.00	0.00
Labor Hours	0.0	0.0	0.0	0.0
Average Labor Cost	0.00	0.00	0.00	0.00
Total Cost (for system)	0.00	0.00	0.00	0.00
Total Cost (for system) per Truck	0.00	0.00	0.00	0.00
Total Cost (for system) per Mile	**0.0000**	**0.0000**	**0.0000**	**0.0000**
Lighting System Repairs (ATA VMRS 34)				
Parts Cost	229.87	492.41	313.36	308.02
Labor Hours	13.4	20.1	19.9	14.6
Average Labor Cost	670.50	1,004.50	994.00	730.50
Total Cost (for system)	900.37	1,496.91	1,307.36	1,038.52
Total Cost (for system) per Truck	180.07	299.38	261.47	207.70
Total Cost (for system) per Mile	**0.0017**	**0.0027**	**0.0024**	**0.0019**

Breakdown of Maintenance Costs by Vehicle System (continued)

	CARB Diesel	ECD™ ECD™ Only	ECD™ Engelhard	ECD™ JMI
Frame, Steering, and Suspension Repairs (ATA VMRS 14-Frame, 15-Steering, 16-Suspension)				
Parts Cost	195.61	1,367.46	882.88	281.02
Labor Hours	57.0	41.5	38.4	23.9
Average Labor Cost	2,849.00	2,074.00	1,921.00	1,195.00
Total Cost (for system)	3,044.61	3,441.46	2,803.88	1,476.02
Total Cost (for system) per Truck	608.92	688.29	560.78	295.20
Total Cost (for system) per Mile	**0.0059**	**0.0062**	**0.0052**	**0.0027**
Axle, Wheel, and Drive Shaft Repairs (ATA VMRS 11-Front Axle, 18-Wheels, 22-Rear Axle, 24-Drive Shaft)				
Parts Cost	127.98	151.78	202.03	161.44
Labor Hours	10.7	10.4	15.6	8.3
Average Labor Cost	534.50	521.50	781.00	417.00
Total Cost (for system)	662.48	673.28	983.03	578.44
Total Cost (for system) per Truck	132.50	134.66	196.61	115.69
Total Cost (for system) per Mile	**0.0013**	**0.0012**	**0.0018**	**0.0010**
Fifth Wheel Repairs (ATA VMRS 59)				
Parts Cost	0.00	0.00	0.00	0.00
Labor Hours	3.2	10.7	3.4	8.1
Average Labor Cost	157.50	537.00	170.00	403.00
Total Cost (for system)	157.50	537.00	170.00	403.00
Total Cost (for system) per Truck	31.50	107.40	34.00	80.60
Total Cost (for system) per Mile	**0.0003**	**0.0010**	**0.0003**	**0.0007**
Tire Repairs (ATA VMRS 17)				
Parts Cost	4,624.52	5,207.24	3,394.12	4,729.62
Labor Hours	15.9	19.8	17.8	24.9
Average Labor Cost	796.00	987.50	888.50	1,245.00
Total Cost (for system)	5,420.52	6,194.74	4,282.62	5,974.62
Total Cost (for system) per Truck	1,084.10	1,238.95	856.52	1,194.92
Total Cost (for system) per Mile	**0.0105**	**0.0112**	**0.0080**	**0.0107**

Notes

1. The engine- and fuel-related systems were chosen to include only systems that could be directly affected by the selection of a fuel.

2. ATA VMRS coding is based on parts that were replaced. If no part was replaced in a given repair, the code was chosen by the system being worked on.

3. In general, inspections (with no part replacements) were only included in the overall totals (not by system). 101 was created to track labor costs for PMA inspections.

4. ATA VMRS 02-Cab and Sheet Metal represents seats, doors, etc.; ATA VMRS 50-Accessories represents fire extinguishers, test kits, etc.; ATA VMRS 71-Body represents mostly windows and windshields.

5. Average labor cost is assumed to be $50 per hour.

6. Warranty costs are not included.

Appendix B

Emission Test Results

Emission Test Results

First Round Emission Testing Results from Ralphs

Test Group	Test ID	Vehicle Type	Vehicle Matrix No.	WVU Vehicle Number	Particulate Filter	Fuel	Driving Schedule	CO (g/mi)	NO_x (g/mi)	HC (g/mi)	PM (g/mi)	CO_2 (g/mi)	MPG (mpg)	BTU (BTU/mi)
CARB	1419	Grocery Truck	1	5915	None	CARB	CSHVR	7.00	36.29	0.210	0.199	1866	5.39	24263
CSHVR	1397	Grocery Truck	2	5917	None	CARB	CSHVR	7.67	43.58	0.223	0.147	1982	5.05	25780
	1444	Grocery Truck	5	5918	None	CARB	CSHVR	5.14	33.53	0.327	0.240	2096	4.78	27194
	1393	Grocery Truck	3	5919	None	CARB	CSHVR	9.63	43.93	0.295	0.208	2119	4.71	27589
	1391	Grocery Truck	4	5920	None	CARB	CSHVR	9.45	47.24	0.309	0.192	1944	5.14	25326
							Average	**7.78**	**40.91**	**0.272**	**0.197**	**2002**	**5.01**	**26030**
ECD	1400	Grocery Truck	6	5910	None	ECD	CSHVR	6.81	38.41	0.214	0.230	1830	5.19	24352
CSHVR	1424	Grocery Truck	9	5911	None	ECD	CSHVR	9.10	29.52	0.155	0.255	1819	5.21	24258
	1436	Grocery Truck	10	5912	None	ECD	CSHVR	5.85	32.04	0.417	0.203	2144	4.43	28488
	1402	Grocery Truck	7	5913	None	ECD	CSHVR	5.85	35.55	0.254	0.171	1866	5.08	24819
	1404	Grocery Truck	8	5914	None	ECD	CSHVR	6.42	37.10	0.237	0.195	1875	5.06	24940
							Average	**6.81**	**34.52**	**0.256**	**0.211**	**1907**	**5.00**	**25371**
DPX	1412	Grocery Truck	11	5905	DPX	ECD	CSHVR(2)	0.05	37.11	0.000	0.003	1816	5.25	24036
CSHVR	1416	Grocery Truck	14	5906	DPX	ECD	CSHVR(2)	0.13	32.26	0.000	0.001	1718	5.56	22744
	1440	Grocery Truck	12	5907	DPX	ECD	CSHVR(2)	0.58	26.26	0.000	0.010	2061	4.63	27283
	1415	Grocery Truck	15	5908	DPX	ECD	CSHVR(2)	0.32	35.05	0.000	0.000	1668	5.72	22077
	1442	Grocery Truck	13	5909	DPX	ECD	CSHVR(2)	0.39	31.16	0.000	0.001	2143	4.45	28367
							Average	**0.29**	**32.37**	**0.000**	**0.003**	**1881**	**5.12**	**24901**
CRT	1427	Grocery Truck	16	5900	CRT	ECD	CSHVR(2)	0.13	32.07	0.000	0.000	2019	4.72	2671
CSHVR	1450	Grocery Truck	20	5901	CRT	ECD	CSHVR(2)	0.11	41.67	0.000	0.004	1981	4.82	2621
	1431	Grocery Truck	17	5902	CRT	ECD	CSHVR(2)	0.11	32.89	0.000	0.004	1797	5.33	2378
	1447	Grocery Truck	18	5903	CRT	ECD	CSHVR(2)	0.11	32.33	0.000	0.005	1906	5.00	25228
	1410	Grocery Truck	19	5904	CRT	ECD	CSHVR(2)	0.15	37.38	0.000	0.000	1702	5.60	22521
							Average	**0.12**	**35.27**	**0.000**	**0.003**	**1881**	**5.10**	**24893**

First Round Emission Testing Results from Ralphs

Test Group	Test ID	Vehicle Type	Vehicle Matrix No.	WVU Vehicle Number	Particulate Filter	Fuel	Driving Schedule	CO g/mi)	NO_x (g/mi)	HC (g/mi)	PM (g/mi)	CO_2 (g/mi)	MPG (mpg)	BTU (BTU/mi)
CARB	1418	Grocery Truck	1	5915	None	CARB	5 Mile Route(2)	2.54	28.41	0.142	0.102	1301	7.70	1687
5-Mile	1398	Grocery Truck	2	5917	None	CARB	5 Mile Route(2)	2.17	39.69	0.166	0.061	1515	6.64	19630
	1394	Grocery Truck	3	5919	None	CARB	5 Mile Route(2)	3.62	36.89	0.184	0.105	1502	6.67	19487
							Average	**2.78**	**35.00**	**0.164**	**0.089**	**1439**	**7.00**	**18662**
ECD Only	1401	Grocery Truck	6	5910	None	ECD	5 Mile Route(2)	2.19	29.87	0.161	0.155	1366	6.97	18128
5-Mile	1403	Grocery Truck	7	5913	None	ECD	5 Mile Route(2)	1.88	28.91	0.171	0.071	1380	6.90	18300
	1405	Grocery Truck	8	5914	None	ECD	5 Mile Route(2)	1.97	25.04	0.160	0.093	1446	6.70	19171
							Average	**2.01**	**27.94**	**0.164**	**0.106**	**1397**	**6.85**	**18533**
DPX	1413	Grocery Truck	11	5905	DPX	ECD	5 Mile Route(2)	0.10	28.63	0.000	0.004	1293	7.37	17111
5-Mile	1438	Grocery Truck	12	5907	DPX	ECD	5 Mile Route(2)	0.13	25.65	0.000	0.001	1422	6.71	18816
	1443	Grocery Truck	13	5909	DPX	ECD	5 Mile Route(2)	0.09	30.47	0.000	0.004	1538	6.20	20355
							Average	**0.11**	**28.25**	**0.000**	**0.003**	**1418**	**6.76**	**18761**
CRT	1428	Grocery Truck	16	5900	CRT	ECD	5 Mile Route(2)	0.16	25.82	0.001	0.002	1470	6.49	19461
5-Mile	1434	Grocery Truck	17	5902	CRT	ECD	5 Mile Route(2)	0.07	28.41	0.000	0.014	1404	6.80	18573
	1448	Grocery Truck	18	5903	CRT	ECD	5 Mile Route(2)	0.11	29.60	0.000	0.008	1583	6.03	20957
							Average	**0.11**	**27.94**	**0.000**	**0.008**	**1486**	**6.44**	**19664**

Second Round Emission Testing Results from Ralphs

Test Group	Test ID	Vehicle Type	Vehicle Matrix No.	WVU Vehicle Number	Particulate Filter	Fuel	Driving Schedule	CO (g/mi)	NO_x (g/mi)	NO (g/mi)	HC (g/mi)	PM (g/mi)	CO_2 (g/mi)	MPG (mpg)	BTU (BTU/mile)
CARB	1551	Grocery Truck	1	5915	None	CARB	5 Mile Route(2)	5.33	25.41	NA	0.156	0.257	1616	6.18	20995
5-Mile	1553	Grocery Truck	2	5917	None	CARB	5 Mile Route(2)	7.81	27.01	NA	0.199	0.279	1653	6.03	21530
	1595	Grocery Truck	3	5919	None	CARB	5 Mile Route(2)	8.35	26.19	24.37	0.226	0.345	1460	6.82	19047
							Average	**7.16**	**26.20**	**24.37**	**0.194**	**0.294**	**1577**	**6.34**	**20524**
DPX	1558	Grocery Truck	11	5905	DPX	ECD	5 Mile Route(2)	2.02	25.31	NA	0.000	0.009	1615	5.89	21409
5-Mile	1562	Grocery Truck	12	5907	DPX	ECD	5 Mile Route(2)	2.75	19.43	12.62	0.000	0.004	1481	6.42	19659
	1563	Grocery Truck	13	5909	DPX	ECD	5 Mile Route(2)	2.79	22.06	15.99	0.009	0.005	1493	6.37	19818
							Average	**2.52**	**22.27**	**14.30**	**0.003**	**0.006**	**1530**	**6.23**	**20295**
CRT	1567	Grocery Truck	16	5900	CRT	ECD	5 Mile Route(2)	0.37	24.23	10.78	0.000	0.005	1482	6.44	19617
5-Mile	1569	Grocery Truck	17	5902	CRT	ECD	5 Mile Route(2)	0.70	22.32	8.44	0.000	0.006	1493	6.38	19772
	1572	Grocery Truck	18	5903	CRT	ECD	5 Mile Route(2)	0.89	20.64	8.47	0.000	0.003	1536	6.20	20341
							Average	**0.65**	**22.40**	**9.23**	**0.000**	**0.005**	**1503**	**6.34**	**19910**

Second Round Emission Testing Results from Ralphs

Test Group	Test ID	Vehicle Type	Vehicle Matrix No.	WVU Vehicle Number	Particulate Filter	Fuel	Driving Schedule	CO (g/mi)	NO_x (g/mi)	NO (g/mi)	HC (g/mi)	PM (g/mi)	CO_2 (g/mi)	MPG (mpg)	BTU (BTU/mi)
CARB	1550	Grocery Truck	1	5915	None	CARB	CSHVR	11.34	33.45	NA	0.203	0.368	2023	4.95	26379
CSHVR	1552	Grocery Truck	2	5917	None	CARB	CSHVR	13.58	36.35	NA	0.252	0.390	2198	4.53	28682
	1591	Grocery Truck	5	5918	None	CARB	CSHVR	13.73	28.64	27.39	0.347	0.660	2015	4.93	26322
	594	Grocery Truck	3	5919	None	CARB	CSHVR	14.06	32.52	33.03	0.276	0.555	1942	5.11	25390
	1593	Grocery Truck	4	5920	None	CARB	CSHVR	13.58	32.25	31.83	0.234	0.555	1991	4.99	26007
							Average	**13.26**	**32.64**	**30.75**	**0.263**	**0.506**	**2034**	**4.90**	**26556**
ECD Only	1554	Grocery Truck	6	5910	None	ECD	CSHVR	11.76	41.56	NA	0.359	0.254	2134	4.43	28488
CSHVR	1587	Grocery Truck	9	5911	None	ECD	CSHVR	9.69	31.21	30.76	0.482	0.195	1846	5.13	24635
	1589	Grocery Truck	10	5912	None	ECD	CSHVR	10.20	35.11	35.67	0.349	0.231	1866	5.07	24907
	1557	Grocery Truck	7	5913	None	ECD	CSHVR	10.29	38.92	NA	0.316	0.266	2175	4.35	28999
	1585	Grocery Truck	8	5914	None	ECD	CSHVR	10.29	30.54	28.24	0.274	0.381	1855	5.10	24765
							Average	**10.45**	**35.47**	**31.55**	**0.356**	**0.265**	**1975**	**4.81**	**26359**
DPX	1590	Grocery Truck	11	5905	DPX	ECD	CSHVR(2)	4.55	32.58	25.10	0.000	0.058	1808	5.26	24015
CSHVR	1592	Grocery Truck	14	5906	DPX	ECD	CSHVR(2)	6.13	30.24	24.16	0.008	0.000	1908	4.97	25381
	1561	Grocery Truck	12	5907	DPX	ECD	CSHVR(2)	5.48	27.61	NA	0.000	0.002	2024	4.69	26894
	1596	Grocery Truck	15	5908	DPX	ECD	CSHVR(2)	4.58	27.37	21.53	0.003	0.006	1898	5.00	25215
	1564	Grocery Truck	13	5909	DPX	ECD	CSHVR(2)	4.71	28.53	21.83	0.000	0.004	2023	4.70	26874
							Average	**5.09**	**29.26**	**23.15**	**0.002**	**0.014**	**1932**	**4.93**	**25676**
CARB	1550	Grocery Truck	1	5915	None	CARB	CSHVR	11.34	33.45	NA	0.203	0.368	2023	4.95	26379
CRT	1568	Grocery Truck	16	5900	CRT	ECD	CSHVR(2)	0.99	35.57	19.16	0.000	0.000	1953	4.88	25869
CSHVR	1581	Grocery Truck	20	5901	CRT	ECD	CSHVR(2)	1.42	34.61	18.91	0.000	0.000	1841	5.17	24397
	1570	Grocery Truck	17	5902	CRT	ECD	CSHVR(2)	1.61	29.10	15.67	0.000	0.001	1956	4.87	25922
	1573	Grocery Truck	18	5903	CRT	ECD	CSHVR(2)	1.38	31.05	15.95	0.000	0.000	1887	5.05	25006
	1619	Grocery Truck	19	5904	CRT	ECD	CSHVR(2)	2.05	38.94	28.86	0.001	0.004	1713	5.56	22716
							Average	**1.49**	**33.85**	**19.71**	**0.000**	**0.001**	**1870**	**5.10**	**24782**

Emission Testing Results from Ralphs

Emission Testing Round	Test ID	Vehicle Type	Vehicle Matrix No.	WVU Vehicle Number	Particulate Filter	Fuel	Driving Schedule	CO (g/mi)	NO_x (g/mi)	HC (g/mi)	PM (g/mi)	CO_2 (g/mi)	MPG (mpg)	BTU (BTU/mi)
Round 1	1484	Grocery Truck	18	5903	None	CARB	CSHVR	11.07	35.11	0.238	0.357	1809	5.50	23612
Round 1	1483	Grocery Truck	18	5903	None	ECD	CSHVR	8.87	28.87	0.215	0.299	1703	5.58	22721
Round 1	1482	Grocery Truck	18	5903	CRT	ECD	CSHVR(2)	0.30	30.57	0.000	0.000	1826	5.23	24176
Round 1	1490	Grocery Truck	19	5904	None	CARB	CSHVR	10.90	37.59	0.324	0.233	1840	5.42	24010
Round 1	1488	Grocery Truck	19	5904	None	ECD	CSHVR	9.12	35.05	0.286	0.161	1751	5.40	23355
Round 1	1487	Grocery Truck	19	5904	CRT	ECD	CSHVR(2)	0.25	33.95	0.000	0.003	1775	5.39	23500
Round 2	1578	Grocery Truck	18	5903	None	CARB	CSHVR	13.35	41.28	0.452	0.347	2015	4.93	26320
Round 2	1574	Grocery Truck	18	5903	None	ECD	CSHVR	12.01	35.84	0.343	0.426	1940	4.95	25716
Round 2	1575	Grocery Truck	18	5903	None	CECD1	CSHVR	11.85	37.71	0.476	0.381	1860	5.07	24886
Round 2	1571	Grocery Truck	18	5903	CRT	CECD1	CSHVR(2)	1.63	31.32	0.000	0.000	1939	4.91	25690
Round 2	1621	Grocery Truck	19	5904	None	CARB	CSHVR	3.83	30.15	0.483	0.135	1921	5.21	24921
Round 2	1583	Grocery Truck	19	5904	None	ECD	CSHVR	9.26	34.13	0.453	0.312	1841	5.14	24559
Round 2	1620	Grocery Truck	19	5904	None	CECD1	CSHVR	4.13	28.51	0.554	0.145	1934	4.91	25696
Round 2	1618	Grocery Truck	19	5904	CRT	CECD1	CSHVR(2)	2.13	37.90	0.013	0.008	1740	5.47	23072

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